STUDY OF THE WORLD BANK HIGHWAY DESIGN AND MAINTENANCE MODEL AND MODIFICATIONS FOR INDIAN CONDITIONS

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by

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CERTIFICATE

Certified that the work presented in the thesis entitled 'Study of the World Bank Highway Design and Maintenance Model and Modifications for Indian Conditions' prepared by Capt Chander Parkash Gupta has been carried out under my supervision and it has not been submitted elsewhere for a degree.

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Chander

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LIST OF NOTATIONS AND ABBREVIATIONS

A	-	Altitude in meters
ADT	-	Average daily traffic
AKM	-	Average annual kilometer driven per vehicle
AKM_O	-	User specified baseline kilometrage driven per year
A_{PASS}	-	Average number of passengers per vehicle
ALTO	-	Null alternative
ALT1	-	Alternative one
ALT2	-	Alternative two
ALT3	-	Alternative three
C	-	Road curvature, in degrees per kilometer
CKM	-	Average cumulative kilometrage of the vehicle group
C_{HOLD}	-	Cargo holding cost per vehicle hour delayed
FA	-	Average fall of the road, in meters per kilometer
$FL=FL_O=FL_C$	-	Fuel consumption at constant speed in litres/1000 km.
GPAV	-	Group paved
GUNP	-	Group unpaved
GVW	-	Gross vehicle weight, in metric tons
HDMO	-	Original version of the highway design and maintenance model based on Kenya studies
HDM1	-	Modified version of HDMO wherein results of RUCS for vehicle operating cost submodel incorporated.

HDM2	-	Modified version of HDM1 wherein traffic interactions also introduced
Km	-	Kilometer
KMPH	-	Kilometers per hour
LH	-	Number of maintenance hours per 1000 km.
mm	-	Millimeter
PC	-	Parts consumption per 1,000 km, expressed as a fraction of average new vehicle cost
P_{COST}	-	Passenger time cost
PV01	-	Paved link number one
PV02	-	Paved link number two
PWR	-	Power to weight ratio, in brake horsepower per metric ton
Q_{PCU}	-	Equivalent passenger car units per hour
R	-	Surface roughness, in millimeters per kilometer
RI	-	Average rise of the road, in meters per kilometer
S	-	Vehicle speed, in kilometers per hour
S_1	-	Operating speed under free flow conditions
SL	-	Depth of loose material, in millimeters
S_0	-	Baseline operating speed, in km/hour
TC	-	Number of tyres consumed per 1000 km.
UP01	-	Unpaved link number one
UP02	-	Unpaved link number two
V_{TIME}	-	Hourly value of time per passenger
W	-	Road width, in meters

β	-	Factor to account for the effect of speed change cycles
ΔFLR	-	Increase in fuel consumption due to road surface roughness, in liters/1000 km.
AASHO	-	American Association of State Highway Officials
CRRI	-	Central Road Research Institute
HDM	-	Highway Design and Maintenance Model
IBRD	-	International Bank for Reconstruction and Development
MIT	-	Massachusetts Institute of Technology
PSI	-	Present Serviceability Index
RUCS	-	Road User Cost Study
TRRL	-	Transport and Road Research Laboratory
UNDP	-	United Nations Development Programme

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SYNOPSIS

In view of the scarce resources which are available to a developing country, it is important that funds for highways be spent in a most judicious manner. Optimal use of national resources will be obtained only when the total highway transport cost is held to a minimum. The Highway Design and Maintenance Model (HDM) of the World Bank is developed as an aid to decision making and can be used to minimize the total cost of transportation on a set of alternative road investments. The types of decisions taken by the model include the choice of alignment, geometric standard, surface type, maintenance policy, and construction and maintenance methods.

Various submodels of the HDM model have been caliberated based on the Kenya study by the Transport and Road Research Laboratory (TRRL). In India not much work has been done to develop the model. The unique features of the Indian Highways cannot be explained by the research carried out in the other countries. Road user cost study (RUCS) in India has done some preliminary work to investigate the road user cost on Indian Highways. The vehicle operating cost submodel and the associated computer programme of the HDM have been modified in the present study based on the RUCS results. Kalka Simla Road has been selected in this study for application of the model. A number of alternate road

investment strategies are selected. Experimental runs are made on the three versions of the HDM model, namely:
(a) original version of the model based on the Kenya studies, HDM0 (b) modified version HDM1, wherein results of the RUCS have been incorporated under the free flow conditions (c) modified version HDM2 wherein effect of traffic interactions is also introduced. The comparison of the different versions is made and the sensitivity of some of the variables is also studied. It has been observed that the modified versions of the model are more relevent to the Indian conditions.

1 INTRODUCTION

1.1 General

An efficient transport system is regarded to be of paramount importance for the economical development of a country. The importance of transport infrastructure and its position in relation to other sectors for the process of economic development are not very clear to the planners.

In the absence of efficient transport infrastructure, the location of economical activities are decided exclusively on natural factors and resources. This has lead to the undesirable regional imbalances. In developing countries with limited resources available for economic development, the choice of investment in transport sector has to compete with other public expenditures like health, education, industry etc. The allocation of available resources among competing alternatives is a complex process. The concepts of project evaluation are fairly well understood and techniques for their application are also well developed. Still the outcome of any particular project evaluation is dependent upon the degree of accuracy and oversimplification involved in assessing the various costs and benefits associated with the project.

1.2 Statement of the Problem

In evaluating investment proposals for the roads, the analyst must address a variety of issues namely: (i) identify the objectives of the project and the extent to which these projects are achieved by a specific proposal, (ii) evaluate the role of a particular link with the development of the overall network, (iii) fit the project in the overall development programme. Within the framework of issues, there is an important subset selection of design and maintenance standard, which is of particular importance to road authorities.

In deciding whether to improve an existing road or not, it may be useful to compare the costs of using and maintaining the existing road against the costs and benefits of constructing, maintaining, and using the new paved road (IBRD, 1971). If the economic return from paving the road is high enough, the project should be recommended. Some other issues of interest can be: should the road be surface treated, or paved with asphaltic concrete? What should be the frequency of improvements and their types for the road to last longer ? Similarly there may be trade offs between initial construction expense and the future costs of using the road. For all these broad range of projects, the engineering solution will have different implications of project costs and benefits. Further because of the high

rates of inflation with respect to the costs of fuel and bitumen, developing nations are steadily losing their purchasing power. The problem that faces the highway authorities more urgently is to find the best way to allocate the limited resources in the face of growing needs. To this end it is desirable to seek a method for selecting projects under budget constraints that fulfills the following requirements (Watanatada, 1980). The method must : (i) be relatively simple and practical, (ii) have a reasonable sound theoretical basis, (iii) not overlook any important trade offs, (iv) be capable of handling the types of projects normally encountered among highway investment projects.

The highway cost model produced by Massachusetts Institute of Technology (MIT) (Moavenzadeh, 1971) is the first effort in recognizing the interrelationships between construction, maintenance, and vehicle costs. The study was successful in highlighting the areas where more research was needed. Transport and Road Research Laboratory (TRRL), UK, in collaboration with the World Bank conducted comprehensive **empirical** study in Kenya (1970 to 1975) and made significant contribution towards firm empirical findings regarding the trade offs amongst construction, maintenance and vehicle operating costs. This is called poineer investigation study (TRRL, 1975).

A more ambitious research project with similar objectives was started in Brazil (UNDP, 1977) in 1975 and has been completed in 1981. The final reports are expected to be published soon. Following the availability of Kenya results, the World Bank co-ordinated an agreement with both TRRL and MIT to produce a unified model. The Road Investment Analysis Model or Highway Design and Maintenance Model (HDM) (World Bank, 1980) is developed as an aid to decision making and can be used to minimize the total cost of transport on a set of alternative road investments. The types of decisions taken by the model include the choice of alignment, geometric standard, surface type, maintenance policy, and construction and maintenance methods. The cost considered include total construction costs; labour, equipment, materials, overhead, and total maintenance costs; normal and generated traffic vehicle operating and travel time costs.

The HDM model of the World Bank, though quite comprehensive, is based on the relationships developed under Kenya conditions. These relationships do not necessarily hold good for highways in India. There is a need to suitably modify the World Bank model for Indian conditions.

1.3 Objectives and Scope of the Study

In 1977 Road User Cost Study (RUCS) was sponsored jointly by the Government of India and the World Bank to

investigate the road user cost on Indian highways (RUCS, May 1977). This study is the first major work done in India and the preliminary results (RUCS, Sep 1981) for some types of vehicles have very recently been made available. There is a need to incorporate the results of the RUCS in caliberating various submodels of the HDM model to make it applicable for Indian conditions. With this objective in mind the vehicle operating cost submodel and the associated computer programmes are proposed to be modified in the present study.

The HDM model does not consider the effects of the traffic interactions and is thus suitable only under the free flow conditions. It is also proposed to incorporate the effect of traffic flow on operating speeds so as to capture the traffic interactions.

Kalka Simla highway, a very important road in the Northern part of India has been selected for the present case study. Relevent input data for this road is collected. A number of alternate road investment strategies are selected. Experimental runs are made on the original HDM model and the modified versions of the model to select the best investment policies. The comparison of different versions of the model is made. The senstivity of some of the variable parameters like traffic growth rate, passenger time value per hour of journey time and maintenance labour cost are also studied.

1.4 Outline of the Report

The structure of the report is as follows: Chapter 2 describes the Highway and Design and Maintenance Model (HDM); Chapter 3 describes the modification of HDM for Indian conditions; Chapter 4 illustrates the case study Kalka-Simla Road and analysis of results; Chapter 5 gives conclusion and recommendations.

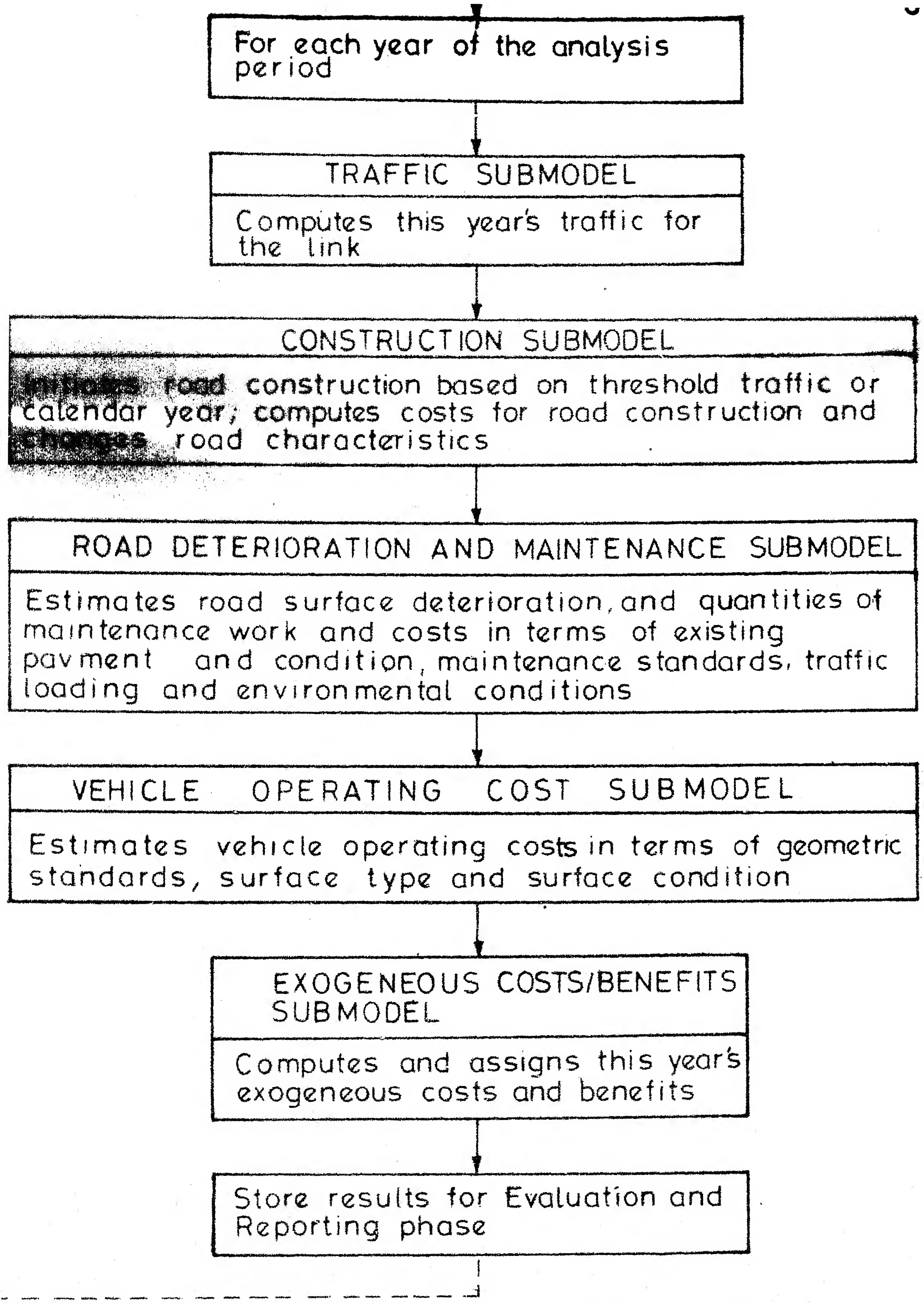
2 HIGHWAY DESIGN AND MAINTENANCE MODEL (HDM) OF THE WORLD BANK

2.1 Introduction

The HDM model predicts the costs of different highway design and maintenance options for a given road project. The model is developed as an aid to decision making and can be used to minimize the total cost of transport on a set of alternative road investments. There is a need to examine and verify the relationships implied in the HDM and determine their suitability to Indian conditions.

The basic function of the model is to estimate construction, maintenance, and user costs for a road which is to be designed, constructed, and maintained to specific standards (MIT, 1977). This is done by simulating the life of the road from initial construction, through periodic upgrading, and through the annual cycle of use, deterioration, and maintenance. The basic structure of the model is shown in Fig. 2.1 (World Bank, 1980). The simulation is accomplished by determining construction and maintenance activities to be performed, and by estimating road conditions, traffic volumes, ancillary investments, and all associated costs on a year-by-year basis throughout the analysis period.

After predicting the condition of the road, the model estimates the cost of road maintenance and vehicle



2.1 SIMULATION OF A LINK ALTERNATIVE
(Source : World Bank , 1980)

operating costs for each year. All these costs are discounted back to the base year and summed over the life of the road to obtain total cost. A more detailed flow diagram of Road Transport Investment Model showing the upgrading and reconstruction options is shown in Fig. 2.2 (TRRL, 674,1975). The various submodels are discussed in the following sections:

2.2 Traffic Submodel

2.2.1 Purpose of the Submodel:- The traffic submodel computes for each year of the analysis period the traffic volumes and the number of equivalent standard axles on the link under analysis. The latter is determined for paved roads only. Traffic volumes are classified in the HDM as either 'normal' or 'generated'.

2.2.2 Normal Traffic:- Normal traffic is that traffic which would use the link regardless of any road improvements, with benefits being calculated as the reduction in operating and travel time costs (MIT, 1977).

The base year average daily traffic for each vehicle class is provided by the user. In addition, different growth rates or annual increments may be specified by the user for each of the vehicle classes and in each traffic period. Normal traffic is then aggregated over all normal traffic sets which are active on this link in the current year, by vehicle class.

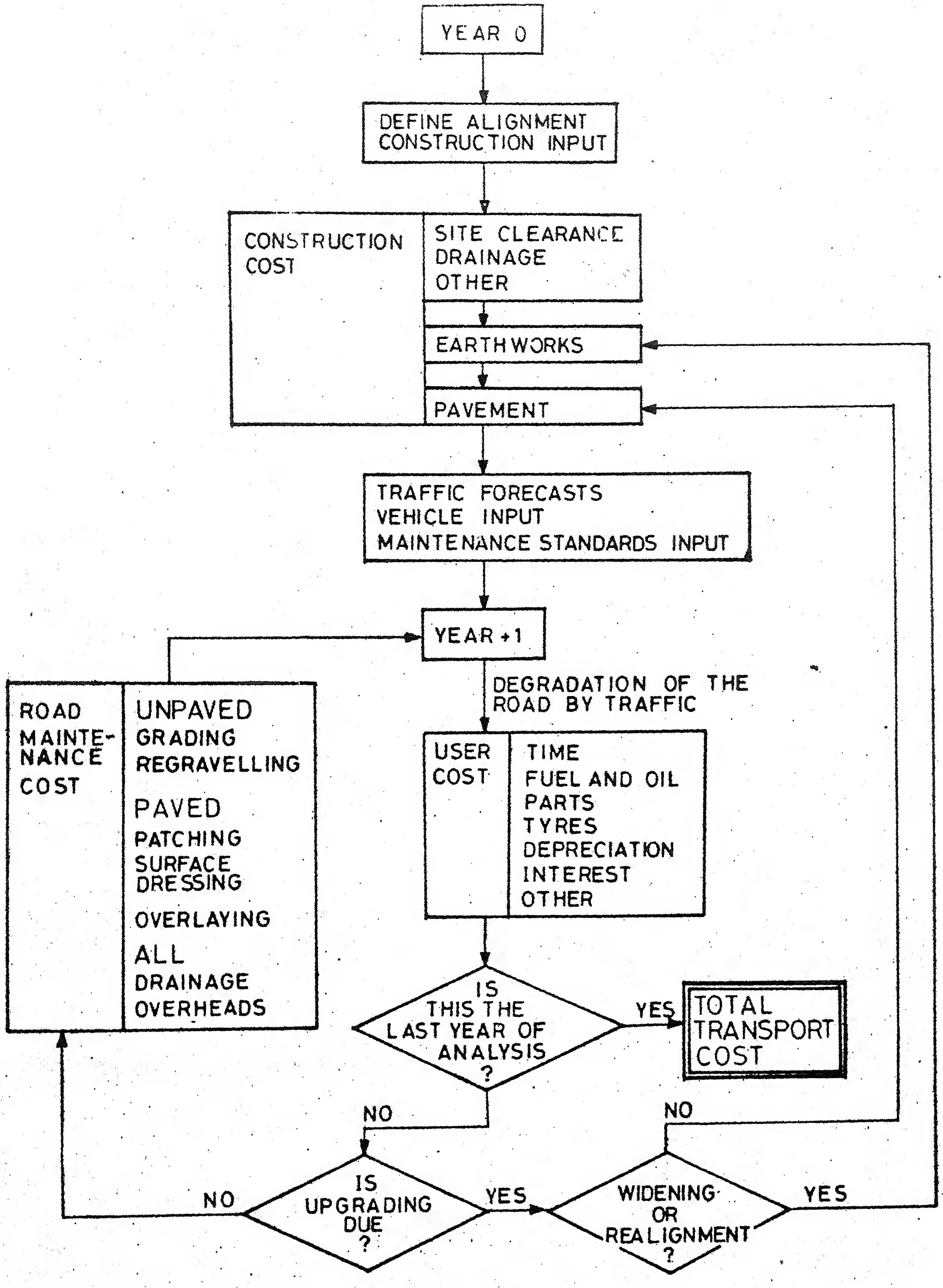


FIG. 2·2 FLOWCHART OF ROAD TRANSPORT INVESTMENT MODEL SHOWING COSTS AND UPGRADING (Source: TRRL, 674, 1975)

2.2.3 Generated Traffic:- It is that traffic which is induced or directed to the link due to changes in the travel time costs of this link and/or neighbouring links. The forecasts of the generated traffic volumes may be given in one of three ways in each of upto three periods of the analysis horizon:

(a) specify an annual percentage growth rate for each vehicle class

(b) specify a constant annual increment for each vehicle class

(c) specify a percentage of current normal traffic for each vehicle class at which this generated traffic will increase each year.

For generated traffic, no base year average daily traffic is provided by the user, since the year of generation be tied to completion of construction projects. Generated traffic is then aggregated over all generated traffic sets which are active on this link in the current year, by vehicle class.

2.3 Construction Submodel

2.3.1 Purpose of the Submodel:- It describes the methods used to estimate construction costs and schedule construction projects. The primary functions of the construction submodel are: (a) to allocate construction costs by cost component

(financial, economic and foreign exchange) on a year by year basis over the duration of the project, (b) to modify the physical characteristics of the link as projects are completed, (c) to activate generated traffic and generated exogenous costs/benefits to the link (if any) as projects are completed.

Projects may be scheduled for any year in the analysis period, and may consists of new construction, pavement reconstruction, widening and so on. Construction costs are input by the user in financial, economic, and foreign exchange terms, alongwith salvage values, and the time distribution of these costs over the project duration. In terms of timing, the assumptions are made that the project starts at the beginning of the year in which it is scheduled, and is completed at the end of the last year.

2.3.2 Type of Improvement and Physical Characteristics:- The projects considered range from new construction to various forms of road improvement. The general characteristics of each project type are as follows:

New construction of a road is the one where either the only existing road is an unimportant earthern track or no road exists.

Pavement overlay is a construction operation consisting only of adding additional material to the surface of the

existing pavement and shoulders. The physical characteristics required are surfacing and conditional data.

Pavement reconstruction includes removal of part or all of the existing pavement structure, and the construction of new base and pavement layers.

Widening existing pavement includes additional site clearing and earthwork, and the extension of culverts and pavement structure. The physical characteristics include geometric, surfacing and condition data.

Widening and reconstruction pavement involves a combination of pavement reconstruction and widening described above.

2.3.3 Physical Features of the Alignment:- Each link can be broken into sections, so that topography, climate, geology and soil types are reasonably similar in a section. The specific variables relevent to the construction submodel are as follows:

The location of each section is defined in terms of its length, starting station, and ending station, in kilometers; and the soil support of the subgrade. These parameters may be affected by new construction or realignment. Soil strength may alter under new construction or realignment.

The geometric features of the alignment include rise, fall, curvature, and width. The choice of standards for

these parameters on any given road: the volume and composition of traffic, the desired capacity of the road, safety, and the overall economics of the project. These decisions are often coordinated through the choice of a design speed. Improved geometric standards (width, curvature, grades) will increase construction costs and reduce operating costs.

Vertical alignment (rise and fall) influence user costs through changes in speed and fuel consumption, and maintenance costs on gravel roads through changes in gravel throwoff. Horizontal alignment (curvature) influences user costs through changes in speed and fuel consumption.

Realignment consists of the construction of a new section of road to correct excessive curvature or grade in an existing alignment. Widening and pavement reconstruction may also be incorporated into this operation.

Surfacing must be specified in terms of material type and thickness for the carriageway and shoulders, the pavement strength, and the deterioration type. The basic types of surfaces which may be considered include earth, gravel, asphaltic concrete and bituminous treated roads.

The condition of the completed pavement surface must be described in terms of its initial roughness and, in the AASHO deterioration types, its initial serviceability, for

paved surfaces only. No condition data need be provided for earth or gravel roads.

The physical characteristics of the affected link are modified to reflect the completed construction activities. For sections where the pavement structure is being modified (new construction, overlay, reconstruction, widening and reconstruction, or realignment) the following data items are modified: pavement name, carriageway type, carriageway thickness, shoulder type, shoulder thickness, structural number, serviceability, roughness, deterioration model type. In addition, the pavement age, cracking, and patching are set to zero.

2.4 Road Deterioration and Maintenance Submodel

2.4.1 Purpose of the Submodel:- The maintenance model computes two types of information essential to the successful operation of the total cost model : (i) maintenance resources and cost (ii) condition of road surface.

The maintenance cost is added directly to the total highway cost. The condition of the road surface is used as an input to the user cost submodel for estimating road user costs. Although maintenance is normally a small portion of total costs, the HDM considers these policies in some detail because vehicle operating costs are significantly affected by road surface condition.

For each year that the road is open to traffic, the model predicts the deterioration of the road surface caused by the vehicular traffic. Having predicted the condition of the road, the model calculates the quantities for each of the maintenance tasks required by the specified policy. Then applies unit costs to determine total maintenance costs for the given year.

2.4.2 Paved Surface Deterioration:- For flexible pavements with granular bases, the general AASHO Road Test results are used. For flexible pavements with stabilized bases, the TRRL Kenya results are used. In either cases, the traffic composition is converted into standard equivalent single axles.

2.4.3 Equivalent Standard Axle Load Factor: - The equivalent standard load factor is defined as the number of applications of an axle carrying a standard load which would cause the same damage to a road as one application of the axle in question. The standard load used here is 18,000 lbs.

2.4.4 Modified Structure Number :- In the analysis of pavement performance a convenient index of payment strength is needed. The index must satisfy the condition that two pavements of the same type having same index will perform identically. The concept of structural number developed during the AASHO Road Test (Moavenzadeh, MIT, 1977) satisfies this requirement, provided that the strength of the

subgrade, the impact of the environment, and the drainage characteristics of the base and sub base are incorporated, establishing a modified structure number.

A satisfactory way of taking into account the strength of the subgrade, the environment impact and the drainage characteristics of the base and the subbase is to modify the structural number of a road of the same type which behaves in the same, but was built in a standard environment on a standard subgrade with standard drainage characteristics. This has been done in both TRRL and AASHO studies.

2.4.5 Deterioration of Flexible Pavements with Granular Base:- Deterioration is predicted as a function of equivalent axle loads and modified structural number. Deterioration is predicted as a drop in AASHO serviceability, PSI, for each year of the analysis period.

The deterioration of pavements with stabilized bases is based on the TRRL Kenya research on road deterioration. All the relationships included in this model are in the form of polynomial equations relating a surface condition variable to traffic loading for a range of modified structural numbers. If the road under consideration is already in existence, the model user must estimate the amount of traffic that the road has carried and the current roughness. If the current roughness is not known, it is assumed that the initial roughness

was 2500 mm/km and the present condition of the road is calculated from the traffic loading. The relationships are not expected to be valid above a traffic loading of 2.5 million equivalent standard axles, and the roads are considered to have failed if the roughness exceeds 4000 mm/km. Therefore if no reconstruction or upgrading has been specified by the model user before these levels are reached, the model prints warning messages, but execution is not terminated.

During the Kenya study, the roads with asphaltic concrete surface on a crushed stone base were also monitored. However, most of the test sections on these roads failed prematurely and could not be used for the derivation of deterioration relationships.

2.4.6 Paved Surface Maintenance:- Maintenance activities are the same in flexible pavements, regardless of base type. The maintenance activities included in the model for paved surfaces are: (a) patching (b) surface dressing (c) overlaying (d) rehabilitation (e) miscellaneous.

Sealing cracks and filling ruts have not been included in the model as maintenance options because the techniques are not in general use of routine maintenance. Excessive cracking is best dealt with by the application of a surface dressing, and excessive rut depth being indicative of pavement fatigue, by an overlay.

Patching:- A reduction in cracked areas will have an effect on future deterioration trends, since water infilteration is reduced. A well placed patch will reduce mean rut depth and yet not contribute to surface roughness.

Surface Dressing:- It is assumed to consist of a seal over entire carriageway surface. The effect on the deterioration parameters is to set cracking and patching to zero. The user may select any level of cracking and patching as a threshold condition demanding surface dressing.

Overlaying:- It is a normal practice to overlay a pavement before base failure occurs. Failure manifests itself through high levels of cracking and roughness. The thickness of carpet which is used to overlay the existing pavement depends on traffic loading of the pavement and the structural condition of the pavement. The use of premix of 50 mm thickness is not recommended, because reflection cracking can cause premature failure which will not be simulated in the model. A new value of the modified structural number is calculated. An overlay also sets the cracking and patching to zero, the cimulative traffic loading to zero, the pavement age to zero, and the roughness to the minimum value for the given surface type; 1500 mm/km for asphaltic concrete and 2500 mm/km for bituminous surface treatment. Also in AASHO model, the rut depth is set to zero and serviceability to 4.2.

Rehabilitation:- The model treats rehabilitation similar to overlaying, only the user specifies the rehabilitated pavements' modified structural number rather than the overlay thickness. The effects are identical to those of an overlay in all other respects.

Miscellaneous Paved Road Maintenance:- It is assumed to consist of drainage maintenance, vegetation control, shoulder maintenance, etc.

2.4.7 Deterioration of Unpaved Roads:- Most of the deterioration relationships for paved roads were derived from the Kenya field data reported by TRRL. Traffic volumes were measured in terms of the total number of vehicles using the road since grading, so that no equivalence factors are employed. Also, pavement strength, the essential, feature of the paved road, cannot be used as an index for unpaved roads, as material is constantly being lost from the surface.

The essential requirement of gravel roads is that they be properly engineered with adequate drainage. The deterioration rates will not apply if these conditions are not met. The quantity of gravel lost from the pavement surface depends on annual rainfall, traffic volume, traffic speed, gravel type and road geometry.

2.4.8 Unpaved Surface Maintenance:- The maintenance activities included in the model for unpaved surface are: (a) dry season grading (b) wet season grading (c) spot regravelling (d) gravel resurfacing (e) miscellaneous.

Grading:- It is specified as days per grading or thousands of vehicles per grading for each of dry and wet seasons.

Spot Regrading:- It may also be done on gravel roads to repair areas of severe gravel loss.

Miscellaneous Unpaved Road Maintenance:- It is assumed to consist of drainage maintenance, vegetation control, shoulder maintenance, safety installations upkeep.

2.5 Vehicle Operating Cost Submodel

Costs are included in two categories: operating costs and travel time costs. Operating costs are those costs incurred through owning and operating the vehicle, and include fuel, oil, tyres, maintenance parts and labour, depreciation, interest, overhead, and crew costs. Travel time costs are relating to the time value of persons and cargo holding costs. Financial costs represent the actual costs incurred to transport operators in owning and operating vehicles over the road. Economic costs represent the real costs to the economy of that ownership and operation, where adjustments are made to allow for market price distortions

such as taxes, labour wage laws, etc. Foreign exchange costs represent the costs which must be provided for in foreign currencies. The environmental input to this model is the mean elevation of the road section above sea level.

2.5.1 Passenger Time Value:- Improvement in a road often results in a reduction in travel time, freeing the passengers for other activities. In addition to freeing the passenger and vehicles, there are often benefits to be gained through reducing the time that the vehicle cargo is in transit. These benefits may be quite large in case of perishable foodstuffs.

2.5.2 Annual Operating Hours:- This figure reflects the number of hours that the vehicle is actually driven in a year. Assuming 2080 work hours in a year (40 hour/week), the actual utilization may be 1500 or 1600 hours for trucks, after allowing for loading operations and repairs.

2.5.3 Vehicle Speed:- The average operating speeds of vehicles using the road are needed in order to estimate fuel consumption and travel time. The speed relationships do not account for vehicle interaction from congestion or speed cycle changes, but do reflect the small effects of reduced road width.

2.5.4 Resource Consumption:- Running costs consists of those costs which are incurred as a direct result of vehicle usage, and include the costs of fuel, oil, tyres, and

maintenance parts and labour. Generally speaking, they vary with vehicle class and age, surface type (paved and unpaved) and condition, design geometry, vehicle speed and driver habits. Fuel consumption equations were developed by TRRL using multiple linear regression techniques. The consumption of oil represents about one percent of the total cost of vehicle usage and, as such, there has been very little research in relating oil consumption rates to either geometry, surface condition, or vehicle age.

2.5.5 Annual Fixed Costs:- The annual fixed costs of vehicle operations include depreciation, interest, crew , and overhead costs. The total costs of these items are assumed as fixed within reasonable ranges around the average annual kilometrage driven, but their allocation on a per kilometer bases will vary with the number of kilometers driven during a year. The model treats crew costs as a fixed annual expense.

2.6 Exogenous Costs/Benefit Submodel

Exogenous costs and benefits are regarded as parallel of traffic sets, in that the forces which give rise to traffic are often the same forces which give rise to production, and hence to exogenous costs and benefits.

2.6.1 Normal Exogenous Costs/Benefits:- These are those costs and benefits streams which would occur in the

vicinity of the link regardless of any road improvements and which are not related to the road itself (construction or maintenance) . Since the cost and benefit growth periods will usually not coincide, each has its growth periods defined separately.

2.6.2 Generated Exogenous Costs/Benefits:- These are those costs/benefits streams which occur due to construction activities on the link, such as increased agricultural production and marketing caused by provision of an all-weather access road. The base year costs and benefits are zero for generated sets. Unlike in normal case, the growth factors are assumed to hold for all years.

2.7 Evaluation and Reporting Phase

This last phase of HDM is used to produce the annual and summary reports, and to perform the economic analysis of the group alternatives to be analysed. Some of the reports are generated automatically, while others must be specifically requested by the user.

2.8 Analysis Procedure

The analysis of alternatives in the HDM model can be summarized in the following steps:

1) For each link alternative, the model assembles financial, economic and foreign exchange annual cost streams including the costs of: construction

investment, road maintenance operations, vehicle running, passenger and cargo delays, and exogenous components for each group alternative.

2) The annual cost streams for link alternatives from Step (1) are summarized for each group-alternative.

3) For each pair-wise comparison of link alternatives the annual benefit and cost streams are computed for one alternative relative to the other in terms of: increases in construction and road maintenance costs; vehicle operating cost and travel time cost savings due to normal traffic; benefits in vehicle operation and travel time savings due to generated traffic; exogenous benefits; and total economic benefits. The total economic benefits are also computed in foreign exchange terms.

4) The cost and benefit streams from step (3) are summarized for each group alternative comparison.

5) The model than computes for each pair wise comparison of link alternatives: the net present value for five discount rates as specified by the user; the internal rate of return; and the first year benefits.

6) Step (5) is repeated for each pair-wise comparison of group alternatives.

For the senstivity studies in which the user specifies percentage increases or decreases for certain cost streams,

steps (3) through (5) above are repeated with the respective cost streams weighted by the user specified factors.

2.9 Computer Programme

The main programme of HDM model is coded in Fortran IV and consists of about 69000 lines with 6 functions and 60 subroutines. The main programme occupies about 2400 blocks and its rel file occupies about 1000 blocks. Catering for the requirement of scratch files for execution, the disc space of about 11000 blocks is required, which is quite high. The model uses standard library subroutines, functions and software features which are mostly available on major compilers. Although the model does not provide a formal mathematical optimization, it does provide the results of economic analysis (total discounted transport cost, rate of return, net present value etc.).

The operations of the HDM model basically fall into three phases. The first phase is the input data editing phase, in which the input data are examined for possible format and numerical errors and internal inconsistences. Any input error in this phase would stop the execution of the remaining phases. The sedond phase is concerned with estimating the costs for each project alternative; construction, maintenance and road user costs and exogenous costs and benefits are each separately calculated. This is done by simulating the lives of the roads from initial construction, through

periodic upgrading and through annual cycles of use. The simulation of a link alternative is shown in Fig. 2.1. The third phase is concerned with economic analysis and comparisons of alternative construction and maintenance policies.

2.10 Uses of the Model

1) There is a large amount of detailed data which can be used as input to the model. However it is not necessary to provide all the data. If certain information is not available, the model will assume appropriate values.

2) The model can be used for any monetary system. At the end of each year, the traffic volumes are compared. If the limiting conditions specified are exceeded, the upgrading or reconstruction is costed and the model continues with the year by year analysis.

3) Individual submodels can be used separately. The construction sub-model can be used to estimate costs and quantities for various projects.

4) The model is very flexible and with very little effort can be used to investigate a large number of routes, maintenance programmes, and combinations of these, which would otherwise be extremely time-consuming and costly to perform.

2.11 Limitations of the Model

It calculates costs to the road user only and does not take account of either secondary economic effects (e.g. increases in agricultural output) or social benefits (e.g. increased mobility). Other minor limitations are discussed below:

1) Before using the model in different environments the data used should be within the range of the Kenyan data.

2) The model calculates the total transport costs for each of the alternative proposals and thus in its simplest form is used to select the best option from a number of alternative solutions. The minimum cost solution is valid only when estimated demand is identical for all alternatives. However construction, maintenance and vehicle operating costs can be used independently to select the best alternative in the solution.

3) The model investigates the cost of an individual link. Road networks can be broken down into individual links and these can be summed to give some measure of network effects.

4) The relationships used in the model to predict vehicle speeds and fuel consumptions were developed under almost free-flow conditions, and they are therefore not valid when traffic interaction takes place.

3. MODIFICATION OF HDM FOR INDIAN CONDITIONS

3.1 Introduction

Highway Design and Maintenance (HDM) model is a unified model combining advantages of models developed by MIT and TRRL based on the Kenya studies. The basic function of the model is to estimate construction, maintenance, exogenous, and user costs for a road which is to be designed, constructed and maintained to specific standards and subject to known traffic volumes and ancillary investments. This is done by simulating the life of the road from initial construction, through periodic upgrading, and through the annual cycle of use, deterioration, and maintenance.

The model predicts the cost of different highway design and maintenance options either for a given road project or for a group of links of a highway network. It estimates total cost for a number of alternative projects on a year by year basis and thus can be used to search for the alternative with the lowest total cost.

Traffic submodel computes for each year the traffic volumes on the link. Traffic volumes are classified as either 'normal' or 'generated'. The relationships used in the model to predict vehicle speeds and fuel consumptions

were developed under almost free flow conditions. Construction submodel is used to predict construction costs and schedule construction projects and to modify physical characteristics of the link as projects are completed. The projects considered range from new construction to various forms of road improvements (MIT, 1977).

Road deterioration model computes maintenance cost which is added directly to the total highway cost. Apart from this, the model also predicts the condition of road surface used as an input to the user cost submodel for estimating road user costs, For each year the model predicts the deterioration of the road surface caused by the vehicular traffic. Vehicle operating cost model calculates costs in two categories: operating costs and travel time costs. Operating costs are those costs incurred through owning and operating the vehicle. Travel time costs are related to the time value of persons and cargo holding costs. Exogenous costs and benefits are regarded as parallel of traffic sets, in that the forces which give rise to traffic are often the same forces which give rise to production, and hence the exogenous costs and benefits. The last phase of the HDM is to produce the annual and summary reports, and to perform the economic analysis of the group alternatives to be analysed.

3.2 Need For Modification

Various submodels of the HDM model have been caliberated based on the Kenya study conducted by the TRRL. The caliberation of these submodels is highly data based and may vary from one country to another even in the developing world. In India not much work has been done to develop the model for estimating the highway transportation cost . Only in 1977 a study named 'RUCS' (Road Users Cost Study) was sponsored jointly by the Government of India and the World Bank to investigate the road user cost on Indian highways. This study is the first major work being done in India and the preliminary results have very recently been made available (RUCS, Sep 1981).

There is a need to incorporate the results of the RUCS in caliberating various submodels of the HDM to make it applicable for Indian conditions. With this objective in mind the vehicle operating cost submodel and the associated computer programmes have been modified in the present study. The modified version of the HDM is more relevent for application to Indian conditions. The results of RUCS as relevent to vehicle operating cost and the modifications of the HDM are discussed in the subsequent sections.

3.3 Special Features of the Indian Highways

A major portion of the road length in the country consists of single lane bidirectional roads. At present 60 percent of National Highway length is double lane, the balance being single lane. The single lane roads are rarely met in countries abroad.

Each crossing or overtaking manoeuvre is accompanied by a reduction in the speed of operation and to travel on the earthen shoulders. This gives rise to greater wear and tear of the tyres, more fuel consumption and greater strain on the mechanical parts of the vehicle (RUCS, Sep 1981).

The traffic on the Indian roads is heterogeneous being composed of fast and slow moving traffic. In addition pedestrians and cattle also are on the roads. The interaction of traffic is a complex phenomenon resulting in reduction in speeds, frequent acceleration and deceleration and movement on earthen shoulder. This results in higher consumption of fuel and lubricants.

Being a labour surplus economy, the emphasis for construction of pavement is on labour intensive techniques with the use of machinery restricted to the minimum. Water bound macadam is a popular specification for earthen roads. The bituminous specifications generally followed for light and medium traffic are surface dressing and pre-mixed carpet.

The provision of bituminous macadam and asphaltic concrete is restricted to a small percentage of the National Highways where the traffic is heavy. Unemployment and underemployment are widely prevalent, the use of the occupant's time in economic analysis is a questionable approach.

3.4 Scope of Road User Cost Study(RUCS) in India

Though extensive work has been done abroad on building highway design models, the models obtained has to be caliberated to make them applicable to Indian conditions. The unique features of Indian Highways cannot be explained by the research carried out in the other countries. The role of RUCS in relation to total highway transportation cost and highway investment criteria is shown in Fig. 3.1. Three important components of the road user cost which the RUCS attempts to evaluate are shown in Fig. 3.2 alongwith the constituents of each component (RUCS, May 1977).

The analysis of the resource consumption as carried out under RUCS is different in many respects. The relationships for these components for both Kenya and India are discussed in the subsequent sections. The units of consumption in the components of Indian study have been kept same by modification of those of Kenya. The total survey period by RUCS was in the range of 12-24 months. A short time of 12 months is likely to miss some important major assemblies and overhauls. Only commercial vehicles viz., trucks and buses are considered by RUCS.

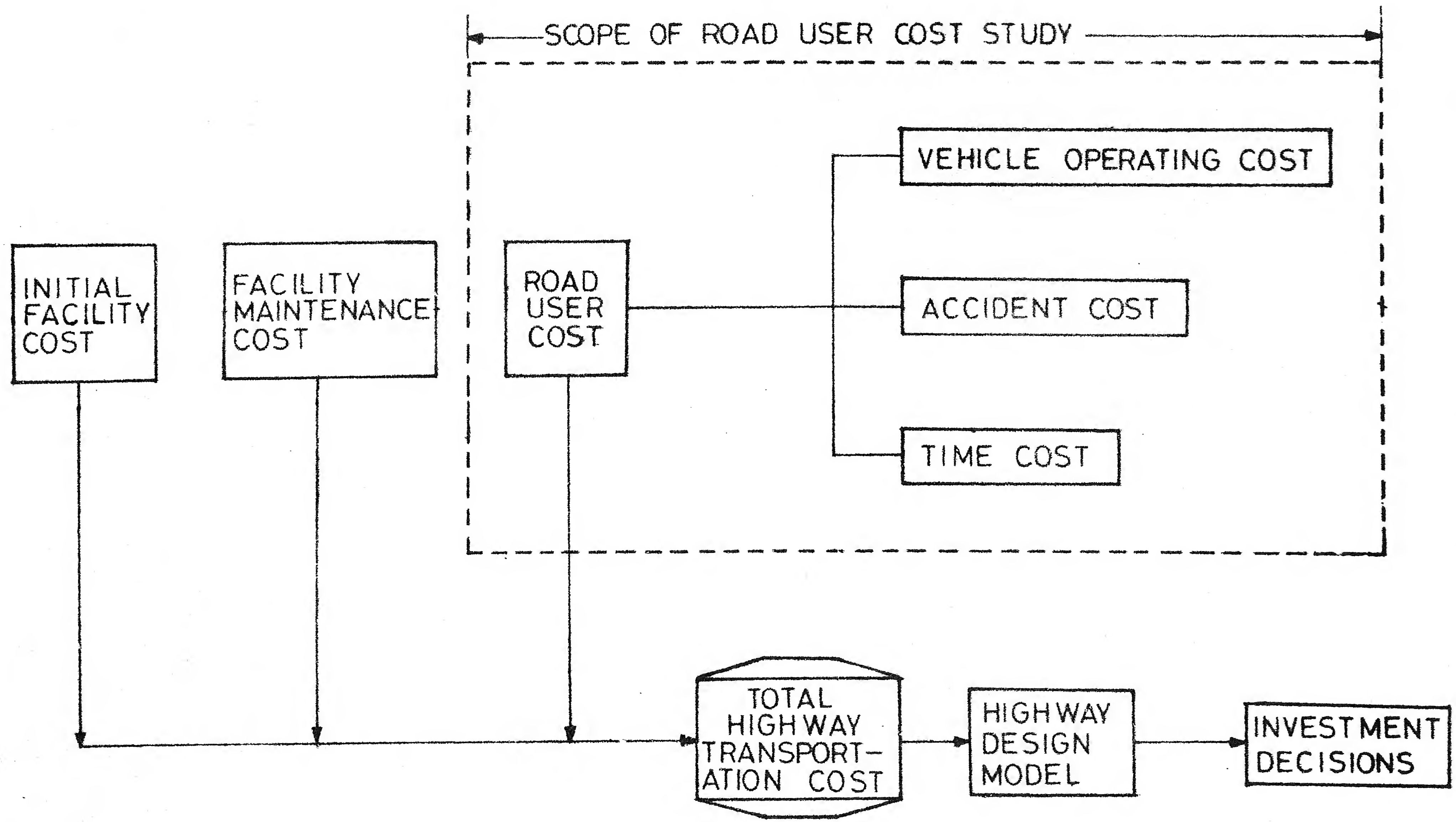


FIG. 3·1 ROAD USER COST IN RELATION TO TOTAL HIGHWAY TRANPORTATION COST AND HIGHWAY INVESTMENT CRITERIA
(Source : RUCS Oct. 1981)

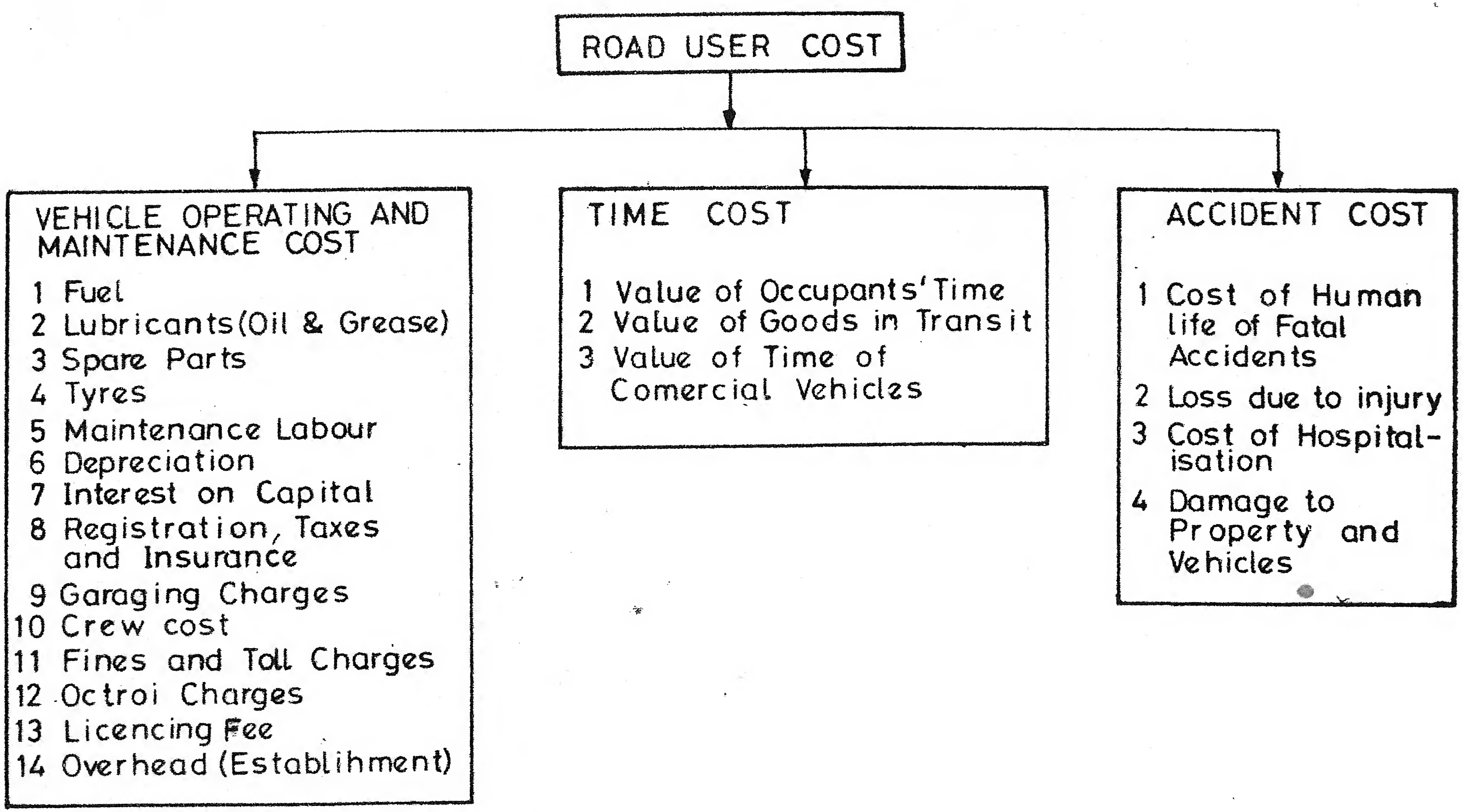


FIG. 3·2 COMPONENTS OF ROAD USER COST
(Source : RUCS Jan. 1982)

3.5 Vehicle Operating Cost Relationships

For buses, heavy and medium trucks RUCS has developed same relationships for speed and fuel but for other resources separate relationships are available. For cars the relationships for speed and fuel have been developed by the RUCS. To include cars in the present study the relationships of Kenya model have been used for other resources. The relationships for heavy trucks for Kenya and India models are discussed below.

3.5.1 Vehicle Speed:

(a) Kenya Study:- The average operating speeds of vehicles plying the road are required for estimating fuel consumption, the unit costs per kilometer of depreciation and interest, and the value of time savings. Speeds are calculated as a function of the average rise and fall, horizontal curvature, road width, altitude, surface roughness and; for unpaved roads, moisture depth, and rut depth (World Bank, 1980).

$$S = 49.80 - 0.51892\ RI + 0.02989\ FA - 0.05801\ C - 0.0006\ R - 0.00042\ A + 1.114\ PWR$$

where S = vehicle speed, in kilometers per hour

RI = average rise of the road, in meters per kilometer

FA = average fall of the road, in meters per kilometer

PWR = power to weight ratio, in brake horsepower per metric ton

R = surface roughness, in millimeters per kilometer

C = road curvature, in degrees per kilometer

A = altitude in meters

The effect of road width less than 5 meters is accounted for by subtracting from the value of speed calculated above an amount, S_W, defined as:

$$S_W = 3.29 (5 - W)$$

where W = road width, in meters.

Because of the linear form of the speed equation the value of the speed computed can possibly be very low or even negative. Therefore, to circumvent this possibility, the minimum speeds are also specified. Curvature is an important factor influencing speed. The speed drops by 5.8 KMPH for every 100 degrees of curvature per kilometer. It is observed that curvature considered for paved and unpaved roads is between 95-240 degrees per kilometer in Kenya models (World Bank, 1980). Whereas for the present case study curvature is between 575-762 degrees per kilometer. The speed will thus reduce by 33-44 KMPH.

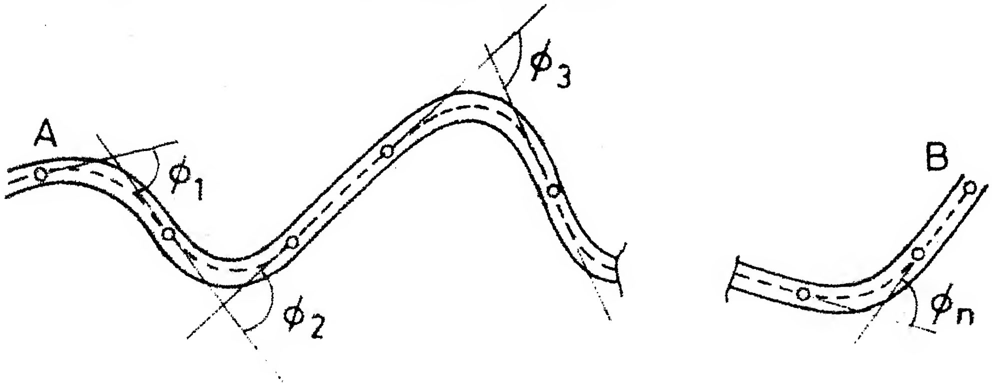
Roughness also affects the speed to some extent. For the present case study where the roughness is between 5000-11000 mm per kilometer the speed will drop in the range of 3-6.6 KMPH. Considering the most dominating factor of rise, the speeds in the present case study are coming out to be negative in most of the cases. In such a situation the minimum speeds specified would be picked up.

Since speed is independent variable in most of the relationships of the vehicle operating costs, the results will be misleading.

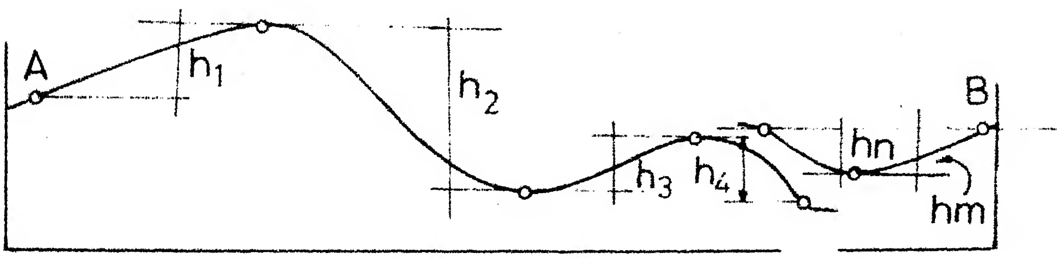
(b) Indian Study:- One of the objectives of the RUCS is to determine the effect of gradient, curvature, pavement surface type, road roughness, width of the carriageway and traffic and environmental conditions on the speed of vehicles. Free speed of any vehicle can be defined as the speed adopted by the driver when not restricted by any other vehicle in the stream under a set of given highway and environmental conditions. Generally, free mean conditions exist at low volume. Free speed conditions exist when overtaking of vehicles or crossing of vehicles in single lane and intermediate lane pavements, do not impede the flow. Traffic volume less than 200 vehicles per hour has been considered for this purpose. This free speed serves as the starting point of the speed-flow curve. The free speed value is the intercept in the speed flow equation. Considering the resources available the effect of the important roadway characteristics were covered only, viz., horizontal curvature, pavement width, roughness of the surface, vertical gradient (rise/fall). Average rise and fall calculations of a section are shown in Fig. 3.3. RUCS considered average operating speeds of various sites for multiple linear regression analysis. The R^2 values range from 0.65 to 0.81 which are reasonable, considering that some of the

PLAN

AVERAGE CURVATURE OF SECTION AB $= \frac{\phi_1 + \phi_2 + \phi_3 + \ldots + \phi_n}{\text{DISTANCE AB (Km)}}$,
EXPRESSED IN DEGREES/Km



LONGITUDINAL PROFILE



AVERAGE RISE OF SECTION AB $= \frac{h_1 + h_3 + \ldots + hm \text{ (Mtrs)}}{\text{DISTANCE AB (Km)}}$,
EXPRESSED IN m/km

AVERAGE FALL OF SECTION AB $= \frac{h_2 + h_4 + \ldots + hn \text{(Mtres)}}{\text{DISTANCE AB(Km)}}$,
EXPRESSED IN m/km

AVERAGE RISE AND FALL OF SECTION

AB $= \frac{h_1 + h_2 + h_3 + h_4 \cdots\cdots + hn + hm\text{(Mtrs)}}{\text{DISTANCE AB (Km)}}$, EXPRESSED IN m/I

IG. 3·3 METHOD OF SPECIFYING THE CURVATURE AND LONGITUDINAL PROFILE OF A SECTION OF ROAD
(Source: RUCS, Jan. 1982)

characteristics were not included (RUCS, Jan 1982).

$$S = 45.92 + 1.1853\, W - 0.2099\, RI - 0.142\, FA - 0.013\, C - 0.0017\, R$$

Curvature is the most dominating factor, it is observed that 100 degrees of curvature per km reduces the operating speeds of a truck by 1.3 KMPH. And for hilly terrain with curvature as high as 1000 degrees per km, the drop in speed of a truck can be in the range of 12-14 kmph. Roughness is the next dominant factor influencing operating speeds. The speed drop between black-topped road with a roughness of 5000 mm/km and a WBM road with a roughness of 15000 mm/km is in the range of 17-25 KMPH. The effect of pavement width is to increase the operating speeds as the pavement width increases. This is quite understandable since drivers would drive at higher speeds on wider roads. The increase in speed per meter increase in the pavement width is 1.2 KMPH.

3.5.2 Fuel Consumption:

(a) Kenya Study

(i) By TRRL

$$FL = \beta\,[\, -48.6 + 903/S + 0.0143\, S^2 + 4.36\, RI - 1.83\, FA - 2.40\, PWR + 69.2\sqrt{GVW} + \Delta FLR \,]$$

where β = factor to account for the effect of speed chan cycles

FL = fuel consumption at constant speed, in litres/1000 km

GVW = Gross vehicle weight, in metric tons

ΔFLR = Increase in fuel consumption due to road surface roughness, in liters/1000 km.

(ii) By Chesher

$$FL_O = \exp [a + BR + CFA]$$

where
$$a = a_o + a_1S + a_2S^2 + a_3R + a_4SL$$
$$B = b_o + b_1S + b_2S^2$$
$$C = C_1 + C_2S + C_2S^2$$

where SL = depth of loose material, in millimeters

(b) Indian Study

$$FL_c = 0.692 - 0.001\ RI - 0.001\ FA + 0.00016\ R + 0.001\ C + 0.052\ W + 0.0698\ GVW$$

From the conclusions drawn from the results obtained by the RUCS, there is an increase of 28 percent fuel consumption when buses operate on WBM single lane roads in plain terrain instead of premix carpet roads. For trucks the increase is 24 percent. A saving in fuel consumption in buses to an extent of 25 percent is possible by asphaltic concrete surface compared to premix carpet surface on a 2 lane road in plain terrain. For trucks, the saving is to an extent of 17 percent (RUCS, Oct 1981).

3.5.3 Spare Parts Cost:

(a) Kenya Study

$$PC = CKM\,[0.48 + 0.00037\,R]\,10^{-8} \quad \text{for } CKM \leq 500{,}000\ \text{Km}$$

$$PC = 500\,[0.48 + 0.00037\,R]\,10^{-5} \quad \text{for } CKM > 500{,}000\ \text{Km}$$

where PC = parts consumption per 1,000 Km, expressed as a fraction of average new vehicle cost

CKM = average cumulative kilometrage of the vehicle group.

(b) Indian Study

$$PC = 0.00172 - 0.000064\,S + 0.000033\,C - 0.00083\,RI - 0.000033\,FA + 0.0000003\,R + 0.000089\,W + 0.00012\,GVW$$

Details of replaced parts i.e. the part that is worn out would often be more important than those of the part that is being substituted. If the two are identical (both new, both second hand or both reconditioned), the actual price paid could be recorded. If the two differ appreciably, the price of the equivalent part would be taken.

3.5.4 Utilization:

(a) Kenya Study

$$AKM = \frac{8760}{\dfrac{8760}{AKM_o} - \dfrac{1}{S_o} + \dfrac{1}{S}}$$

where, AKM = average annual kilometer driven per vehicle

AKM_0 = user specified baseline kilometrage driven per year

S_0 = baseline operating speed, in Km/hour

(b) Indian Study

$$AKM = [454.46 + 4.06\ S + 0.026\ C - 1.98\ RI - 1.98\ FA - 0.042\ R - 4.16\ W]\,365$$

The utilization of vehicles increases spectualarly as road conditions improve. When a single lane road is widened to an intermediate width in plain terrain, the utilization of trucks jumps up from 285 to 303, when it is further widened to two lanes the utilization increases to 320, Improvement of the surface to asphaltic concrete further increases the utilization to 451.

3.5.5 Tyre Life:

(a) Kenya Study

$$TC = GVW\ [83+0.0112\ R\ ]\ 10^{-4} \quad \text{for } R \geq 1500 \text{ mm/Km}$$

$$TC = 0.01\ GVW \quad \text{for } R < 1500 \text{ mm/Km}$$

where TC = number of tyres consumed per 1000 Km.

(b) Indian Study

$$TC = 1/11.473 - 0.2205\ C - 0.2349\ RI - 0.2349\ FA + 0.00066\ R + 0.9898\ W$$

The life of tyres of trucks in plain terrain increases as the road is improved. The life is 34,934 Km on a single lane WBM

road, as found out by RUCS. It increases to 41;318 when the surface is made premix carpet. When it is further widened to an intermediate width, the tyre life increases to 43,046. Conversion to a two lane width brings about an addition of 1481 Km to tyre life. The conversion of the premix carpet surface to asphaltic concrete further enhances the tyre life by 4788 Km. Tyre is an important component of the vehicle running costs. Since tyres are sometimes taken from one vehicle and fitted to another, it would be necessary to keep track of each tyre fitted to each sample vehicle. The life of a new tyre fitted on commercial vehicle may be in the range of only 4-6 months.

3.5.6 Maintenance Labour Hours:

(a) Kenya Study

$LH = PC\,[\,2975 - 0.078\,R\,]$ for $R \leq 6000$ mm/Km

$LH = 2507\,PC$ for $R > 6000$ mm/Km

where LH = number of maintenance hours per 1000 Km.

(b) Indian Study

$$LH = 24.458 - 0.51\,S + 0.0175\,C - 0.30\,RI - 0.30\,FA - 0.0035\,R + 0.045\,W + 0.762\,GVW$$

The labour hours involved in repairs and maintenance decreases remarkably as the road is progressively improved. For a WBM single lane road in plain terrain, the labour hours involved are 37.26 hrs, whereas it drops down to 23.26 when the single

lane is provided with a premix carpet surface. The labour hours decrease from 23.41 for a two lane road i.e. two lane road with premix carpet surface,to 12.91 for a two lane road with asphaltic concrete surface.

3.5.7 Oil Consumption:

(a) Kenya Study

As the consumption of lubricating oil comprises less than one percent of total vehicle operating cost, little research has been conducted to relate oil consumption to vehicle speed, and road characteristics. The following rates, obtained from the TRRL- Kenya study, are used in the model:

Oil consumption rates (liters per 1000 km)

Heavy goods vehicle = 4.0

(b) Indian Study

$$OIL = -14.78 + 0.04\ S + 0.0138\ C - 0.095\ RI$$
$$-0.095\ FA + 0.003\ R + 0.74\ W + 0.31\ GVW$$

The consumption of oil also shows reduction as the road is progressively improved. The data for oil is collected in two distinct parts.

(i) Oil consumed during vehicle running i.e. the additional oil required to be added to the engine every now and then between complete engine oil changes when the vehicle is on the road.

(ii) Maintenance oil changes i.e. complete oil changes of the engine which are carried out under normal maintenance policy of the operator.

3.6 Travel Time Cost

Travel time cost = passenger time cost + cargo holding cost

(a) Passenger Time Cost (P_{COST})

$$P_{COST} = \frac{A_{PASS} \times V_{TIME}}{S}$$

where, A_{PASS} = average number of passengers per vehicle

V_{TIME} = hourly value of time per passenger hour.

(b) Cargo holding cost (C_{COST})

$$C_{COST} = \frac{C_{HOLD}}{S}$$

where C_{HOLD} = Cargo holding cost per vehicle hour delayed.

The average vehicle speeds used in these relations is the modified speed after taking into account the speed-volume effect.

3.7 Effect of Speed on Volume

The operating speeds of vehicles are required to estimate fuel and oil consumption, vehicle utilization, travel time cost etc. In the TRRL relationships for speed as used in HDM, the speed is calculated as a function of road

geometrics and vehicle types (refer 3.5.1). These speed relationships are valid only under free flow conditions. In reality the operating speed of a vehicle is also a function of traffic flow and its composition. TRRL relationships are not valid when traffic interactions take place. Even on roads which may have free flow conditions in the starting period of analysis, the increased traffic flow in later years builds up the traffic interaction. Determination of speed flow relationships is of fundamental importance. In India there is a large proportion of single and intermediate lane highways and traffic is of mixed nature. The fast moving vehicles also occupy the same space as the slow moving vehicles. The condition of shoulders is also substandard. The traffic interaction in such complex conditions builts up even at low traffic flows (RUCS, Oct 1981).

RUCS attempts to estimate the speed flow relationships for different highways using empirical and simulation models. This study is still in progress but some of the preliminary results have been published. Looking at the fundamental importance of speed relationships considering traffic interactions, the HDM relationships are modified as follows to suit the Indian conditions:

(a) The operating speed of vehicles is estimated under the free flow conditions where the only constraints are the

physical characteristics of the road and the characteristics of the vehicle. The RUCS relationships are already explained in para 3.5.

(b) The operating speed of a vehicle considering traffic interactions, is estimated as follows:

$$S = S_1 - a' \cdot Q$$

where S = operating speed considering the effect of traffic flow

S_1 = operating speed under free flow conditions,

a' = regression coefficient.

Based on the preliminary analysis the operating speed relationship by RUCS is as follows:

$$S = 48.28 - 0.00534\, Q_{PCU}$$

where Q_{PCU} = equivalent passenger car units per hour.

HDM estimates the average daily traffic of different vehicle types for every year of the simulation experiment. There are variations in the hourly traffic volume during the day. Some of the studies indicate that the peak hourly flow is 8 to 12 percent of the average daily traffic. In the present study the hourly traffic volume is taken as 10 percent of the average daily traffic and the operating speed is obtained by the following relationship:

$$S = S_1 - 0.00534\ \frac{ADT}{10}$$

where ADT = average daily traffic.

Once the complete analysis of the RUCS study is available the speed relationship may be modified. The modifications of the HDM model considering the effect of traffic interactions is more realistic for the Indian conditions.

3.8 Modifications of the Computer Programme

The computer programme of the HDM model is quite long having about 69000 lines including 6 function and 60 subroutines. The programme was implemented on the DEC 1090 system by making the necessary changes. A sample input data supplied by the World Bank was used for an experimental run. The output on DEC 1090 system matched with sample output obtained from the World Bank. To modify a programme of this magnitude requires thorough understanding of the programme. Considerable effort and time has been spent in understanding various subroutines and functions. The subroutines and functions meant to detect format and data errors consumed lot of time. The computer programme of the HDM requires around 11000 blocks during execution with large memory space. A great deal of co-ordination was done at various stages.

All the modifications in the vehicle operating cost submodel as discussed in the preceding sections have been incorporated in the HDM model. Experiments are made

on the following three different versions of the model to compare the outputs.

(a) Original version of the model based on Kenya studies (HDMO).

(b) Modified version HDM1, wherein results of the RUCS for vehicle operating cost submodel has been incorporated under free flow conditions.

(c) Modified version HDM2, wherein effect of traffic interactions is introduced.

4 A CASE STUDY - KALKA SIMLA ROAD

The study and behaviour of Highway Design and Maintenance Model on Indian conditions for the present study involved two approaches. One approach was to identify certain portion of highways in the country each with plain or rolling or hilly terrain features and collect data for the past few years. The second approach was to select one road having all types of terrain. An ideal location for the case study, keeping in view the resources of time and effort, is the Simla-Kalka road having rolling and hilly features. The case study gives an account of the performance of original model and modified versions for the Indian conditions.

4.1 Description of the Road

The Simla-Kalka Road (National Highway) is one of the important arteries of traffic from various parts of the country to the hill capital of Himachal Pradesh. The total length of the road is 84 kms. The extremes of curvature and gradient to the moderate values are offered by this road. In view of the good mixture of different levels of road geometry, the road offers the best possibility for a comparative study of results under the different road conditions. Apart from the main Simla-Kalka road two more road links have also been considered as follows:

(i) Simla-Kalka Road Via Solan divided into two links:-

(a) Simla to Solan (PV01) 42 km, paved.

(b) Solan to Kalka (PV02) 42 km, paved.

(ii) Simla to Solan via Mashobra (UP01), 65 km, unpaved gravel.

(iii) Simla to Solan via Jutog (UP02), 56 km, unpaved earthen.

The plan layout of all the links is shown in Fig. 4.1. The main links PV01 and PV02 are paved two lane block topped with 1 meter shoulder on either side on an average. Hence, the pavement width and type of shoulder can be assumed to be constant throughout the stretch. Sight distance was not measured for the data. However, as sight distance is closely related to the geometry and the horizontal profile and can be represented by proxy by these. The two paved and two unpaved links have been put into separate groups indentified as group Identification(ID) codes GPAV and GUNP, respectively. These links are subject to a variety of alternate road construction and maintenance policies, as summarized below :

GPAV	PV01 and PV02	ALT0	Existing road maintenance standards
		ALT1	Improved standards with rehabilitation
		ALT2	Improved standards with overlaying
		ALT3	Improved standards with overlaying and more intensive routine activities

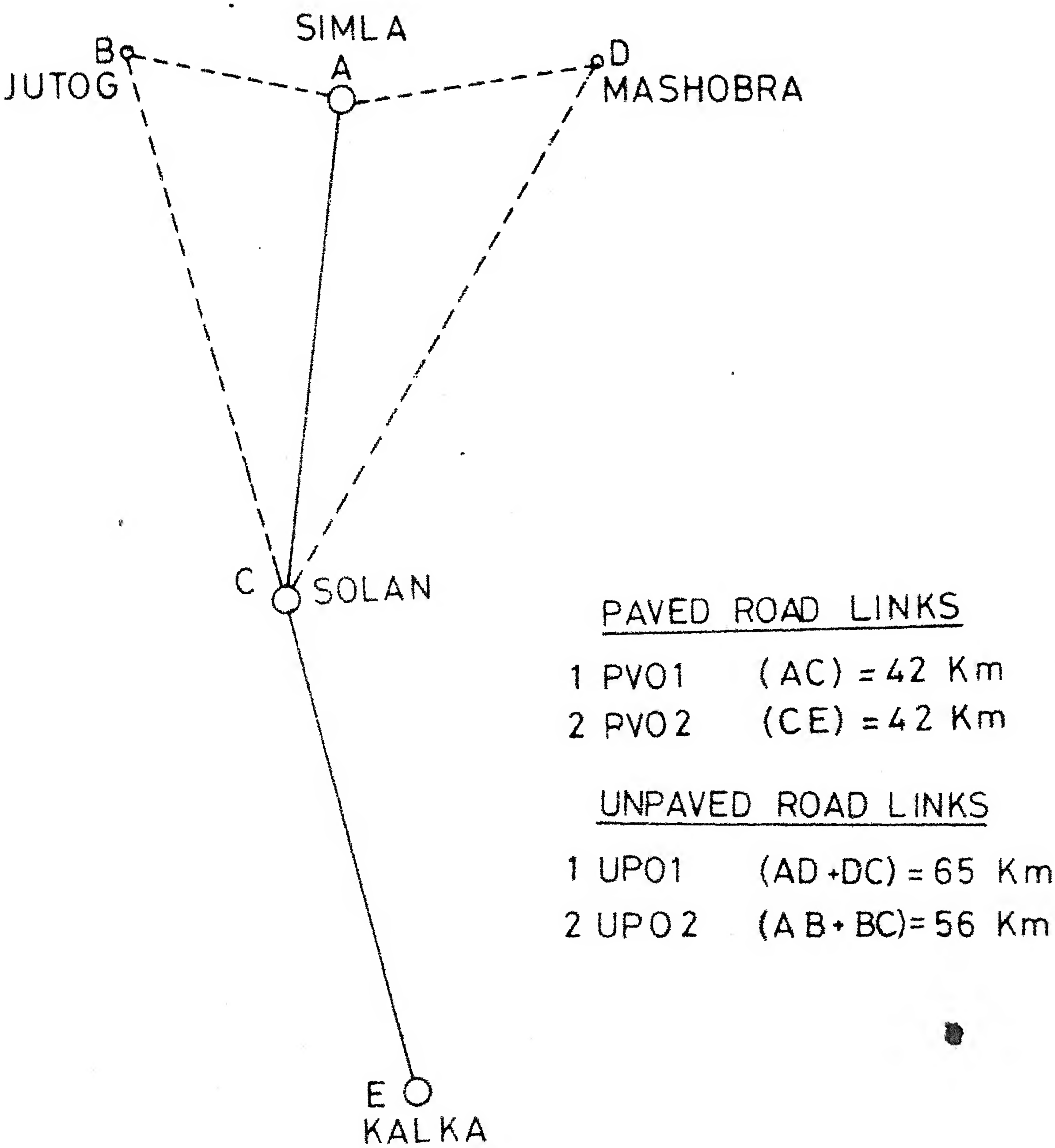


FIG. 4·1 LAYOUT OF ROADS

GUNP	UP01 (Gravel)	ALT0	Existing gravel road maintenance standards
		ALT1	Upgrading to paved status without geometric improvements
		ALT2	Upgrading to paved states with geometric improvements
	UP02 (Earthen)	ALT0	Existing earth road maintenance standards
		ALT1	Improved standards- low level
		ALT2	Improved standards-medium level
		ALT3	Improved standards-high level

4.2 Data Collection

4.2.1 Paved Roads:- Most of the data regarding environment, road geometry, surface conditions, history, unit costs of maintenance and other operations, and vehicle characteristics was available from Central Road Research Institute (CRRI) and Himachal Pradesh State PWD divisions (Noted from the records maintained by the office) at Simla and Solan. The following data was not available:

(a) Condition of Roads

(i) Rut depth (in mm)

(ii) Looseness (in mm)

(iii) Cracking of surface (sqm/km)

(b) Unit costs are available on 1979 schedule of rates. About 80 to 100 percent increase in unit costs for various road projects has taken place since then. However, 100 percent increase has been assumed uniformly for all types of road works.

(c) Vehicle Characteristics

(i) Maintenance labour cost per hour

(ii) Passenger time cost per passenger hour delayed

(iii) Cargo time cost per vehicle hour delayed

(iv) Growth rates for all vehicle types.

The values of all these items have been assumed suitably and given in the section 4.3.

4.2.2 Unpaved Roads:- Only yard stick rates per kilometers or cubic units for various projects are available on 1979 schedule of rates. The alignments of both the earthen and gravel road links have been taken off the map for the purpose of the present study.

4.3 Data Series

The HDM model requires the input data to be given in the form of 11 series namely 'A' to 'K' described as follows (World Bank, 1981):

Data series 'A' describes the existing link characterist and conditions of road section at the begining of the analysis

period. Series 'B' is about construction options and costs i.e. if there are any changes to be made in the form of construction improvements etc. Series 'C' specifies the alternative maintenance standards to different types of road surface and road maintenance unit costs. Series 'D' describes the vehicle characteristics and unit costs of different types of vehicles. Series 'E' gives an account of characteristics of vehicular traffic in terms of base year volume and composition. Apart from this, growth and induced traffic characteristics are also given. Series 'F' incorporates exogenously calculated benefits and costs other than construction, maintenance, and vehicle operating costs. Series 'G' specifies alternative set of construction and maintenance policies. Series 'H' specifies grouping of these link alternatives for economic analysis. Series 'I' is to request for different forms of reports on financial costs, maintenance work done with costs, vehicle operating cost, and road surface conditions for link and group alternatives. Series 'J' is for specifying the comparison of link and group alternatives. In the end series 'K' is to provide global parameters for the model run and specifications for data input. With the analysis period for the sample run covering 12 years from 1983 to 1994, a set of data series 'A' to 'K' are given in Appendix 'A' for the present case study.

4.4 Experimental Runs

After incorporating the various changes in the model as discussed in Chapter 3, the following three versions of the model are available for experimental runs:

(i) The original HDM model (HDMO)

(ii) Modified model (HDM1), wherein the results of the RUCS for vehicle operating cost have been incorporated but no effect of traffic interactions on speed is considered (Free flow conditions).

(iii) Modified model (HDM2) including HDM1 and the operating costs considering the effect of traffic interactions.

The last version is more realistic for application on highways in India. It was proposed to evaluate the sensitivity of the above three versions for the case study. There are certain parameters whose values are not available for the case study, these include:

(i) traffic growth rate for different types of vehicles,

(ii) value of passenger time per journey hour for different vehicles,

(iii) value of maintenance labour per hour for different vehicles.

Some estimates of these parameters have been made on the available information. It is proposed to evaluate the

senstivity of these factors. Two levels were identified for each of the three factors. A full factorial design requires eight experimental runs to be made. But due to various constraints on the computation time a fractional actorial design of four experiments was selected for analysis. The details of these experiments are given in Table 4.1.

For each of the experimental design, runs are made for every version of the model viz. HDM0, HDM1 and HDM2. In all twelve experimental runs were made. Each run of the experiment for four link alternatives and twelve years simulation period requires 11000 blocks of disc space on DEC 1090 system to store the various scratch and output files for execution. Due to various constraints of available computer memory, CPU time, and disc space only twelve experimental runs were performed.

4.5 Analysis of Model Output

There is a need to incorporate the results of the RUCS in caliberating various submodels of the original model HDMO to make it applicable for Indian conditions. The modified versions HDM1 and HDM2 are more relevent to the Indian conditions. In the subsequent sections all the three models viz., HDMO, HDM1 and HDM2 have been analyzed with respect to their operating cost, travel time cost, and mean speeds etc.

TABLE 4.1

LEVELS OF PARAMETERS

S. No.	Parameters	Levels	Values for different types of vehicles			Remarks
			Car	Bus	Heavy Truck	
1.	Passenger time cost per hour journey time (Rupees per hour)	(a) A_1	9	3	-	
		(b) A_2	12	5	-	
2.	Maintenance labour cost (Rupees per hour spent on maintenance)	(a) B_1	10	15	14.0	
		(b) B_2	6	8	7.5	
3.	Growth rate (percentage per year)	(a) C_1	12	15	20.0	from 1983 t 1985
			20	15	16.0	from 1986 t 1994
		C_2	26	26	30.0	from 1983 t 1985
			14	15	20.0	from 1986 t 1994

4.5.1 Comparison of Results from HDMO and HDM1 Model Versions:- The average operating speeds obtained from the two model versions are given in Table 4.2. The results of the average operating speed studies carried out by RUCS in 1981 (RUCS, 1981) at various locations on Kalka-Simla road are given in Table 4.3. The values of speed obtained from HDMO are considerably lower than the actual values, whereas the values obtained from HDM1 compare well with the field observations.

The vehicle travel time cost is the dominating factor in determining the highway benefits. The comparison of the values by the two models for an alternative is given in Table 4.4. As observed from the table, the values for the first few years given by HDM1 decreases because of the project taken up in 1983, for later years the values increase with time and traffic volume. The T-test details in Table 4.5 indicates that the HDMO values are considerably high in all alternatives at 5 percent level.

The vehicle operating costs, like the vehicle travel time costs given by HDMO version, are higher than that of HDM1. The ratio of the two costs varies between 2.26 to 2.74 for an alternative given in Table 4.6. The higher values of the operating costs (which includes resources consumed by the vehicles) in the HDMO version are because of more

TABLE 4.2

AVERAGE SPEED ON LINK 1001 (PV01)

(HDMO VS HDM1)

Year	Traffic Volume	Average Speed (Km/hour)			
		Pass Car		Larg Bus	
		HDMO	HDM1	HDMO	HDM1
1984	2678	22.8	54.4	17.5	44.1
1985	3418	22.0	52.2	16.9	42.6
1986	3991	20.0	45.3	15.3	37.9
1987	4663	20.0	46.2	15.5	38.5
1988	5452	20.0	39.5	15.0	34.0
1989	6377	20.0	43.1	15.0	36.4
1990	7464	20.0	43.6	15.0	36.7

HDMO - Original Kenya model

HDM1 - The vehicle operating cost submodel of HDMO modified for Indian conditions.

TABLE 4.3

AVERAGE OPERATING SPEED VALUES BY RUCS IN 1981

Average Operating Speed Ranges		
Car	Bus	Truck
30.23 to 48.52	24.69 to 42.91	23.06 to 39.94

TABLE 4.4

COMPARISON OF VEHICLES TRAVEL TIME COSTS BASED ON KENYA AND INDIAN MODELS

Year	Traffic Volume	Travel Time Cost		HDMO / HDM1	Remarks
		HDMO	HDM1		
1983	2099	123.994	76.98	1.63	PV01- ALT0
1984	2678	156.232	54.306	2.88	
1985	3418	196.852	71.013	2.77	
1986	3991	227.245	92.800	2.45	
1987	4663	262.346	105.239	2.49	
1988	5452	302.887	139.075	2.18	
1989	6377	349.714	148.775	2.35	
1990	7464	403.805	170.497	2.37	
1991	8741	466.289	197.866	2.36	
1992	10243	538.473	213.614	2.52	
1993	12010	621.867	257.848	2.41	
1994	14089	718.218	341.842	2.10	

HDMO - Original Kenya Model

HDM1 - The vehicle operating cost submodel of HDMO modified for Indian conditions.

TABLE 4.5

T-TEST HDMO VS HDM1 VEHICLE TRAVEL TIME COST

Degrees of Freedom	Mean		T-Statistic	't' from Tables at 5 percent level	Remarks
	HDMO	HDM1			
22	363.916	225.000	2.204	1.717	Significant at 5 percent level for all alternatives for PVO1 and PVO2
22	363.916	235.250	1.973	1.717	
22	363.916	155.666	3.463	1.717	
22	363.916	191.250	2.887	1.717	
22	363.916	207.000	2.521	1.717	
22	363.916	297.568	2.975	1.717	

weightage given to curvature and roughness for estimating the resources. The estimated operating speeds of the vehicles in the HDMO version are quite low which result in more resource consumption. Results given in Table 4.6 indicate that the ratio of the two operating costs decreases over time. Operating cost includes cost of resources consumed by the vehicle which depend upon a large number of parameters. The detailed investigation about the effect of different parameters on the two model versions was not investigated. The trend in the ratio of the two operating costs may be because of increased traffic volume over time. The relationship between the ratio of the operating costs versus traffic volume is shown in Fig. 4.2. The ratio increases exponentially with increase in the traffic volume.

The frequency distribution of the operating cost of two versions for all the alternatives put together is shown in Fig. 4.3. This indicates that the operating cost by HDMO on an average is 2.54 times of the operating cost given by HDM1 with a variance of 0.413. The various percentile of the ratio are also shown in the Fig. 4.3. Comparison of the operating costs is also done by T - statistic and the results are given in Table 4.7. The results indicate that the values obtained by HDMO are quite high at 5 percent level.

In view of this discussion it can be said that the results of HDMO are considerably higher than those of HDM1.

TABLE 4.6

COMPARISON OF VEHICLE OPERATING COSTS BASED ON KENYA AND INDIAN MODELS

Year	Traffic Volume	Vehicle Operating Cost		HDMO / HDM1	Remarks
		HDMO	HDM1		
1983	2099	150.773	66.665	2.26	PV01-ALTO
1984	2678	190.771	82.912	2.30	
1985	3418	242.966	104.351	2.33	
1986	3991	283.961	119.796	2.37	
1987	4663	332.338	137.796	2.41	
1988	5452	389.204	158.578	2.45	
1989	6377	456.042	182.549	2.50	
1990	7464	534.594	210.170	2.54	
1991	8741	627.557	242.499	2.59	
1992	10243	736.697	279.597	2.63	
1993	12010	864.951	322.221	2.68	
1994	14089	1015.804	371.254	2.74	

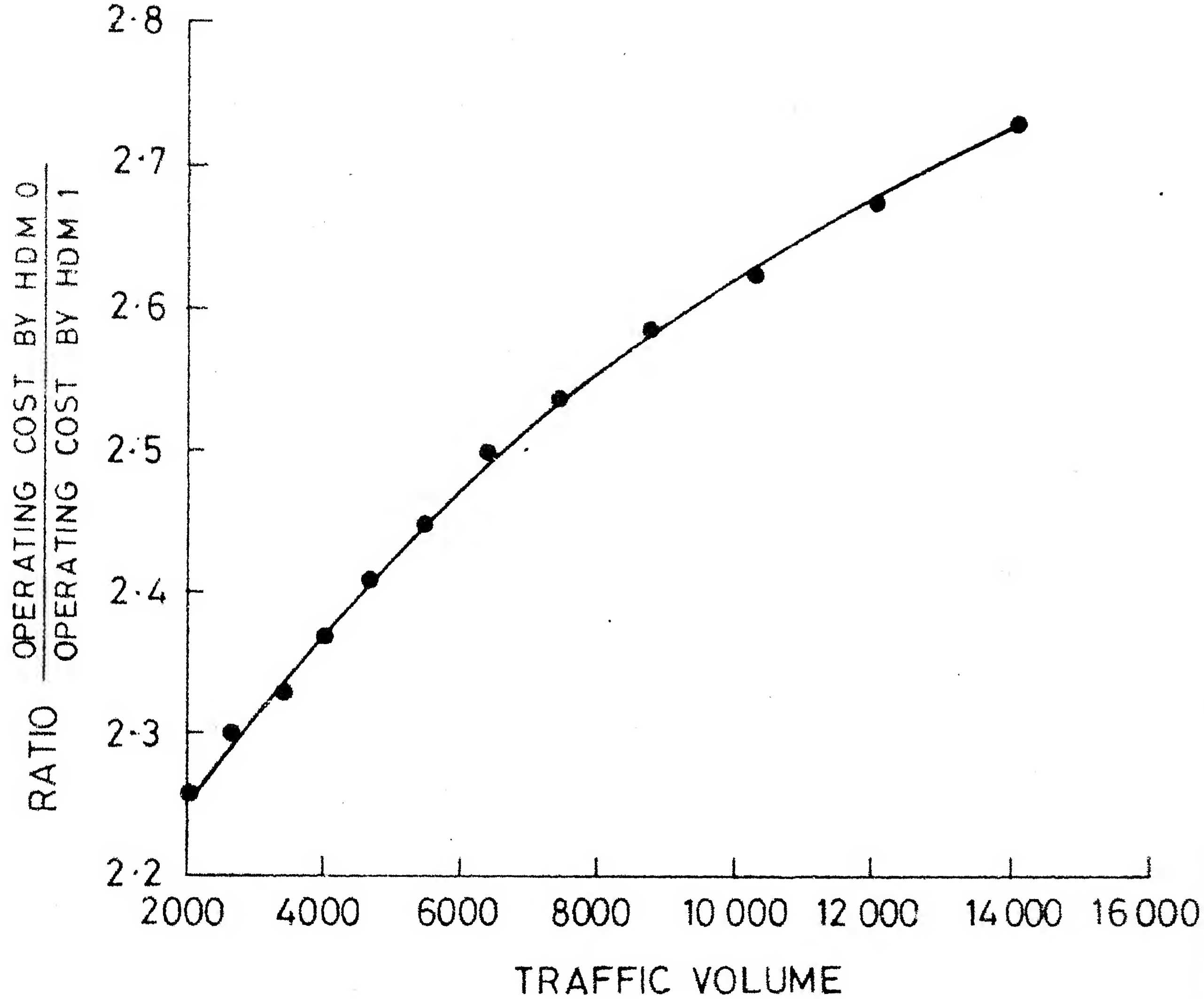
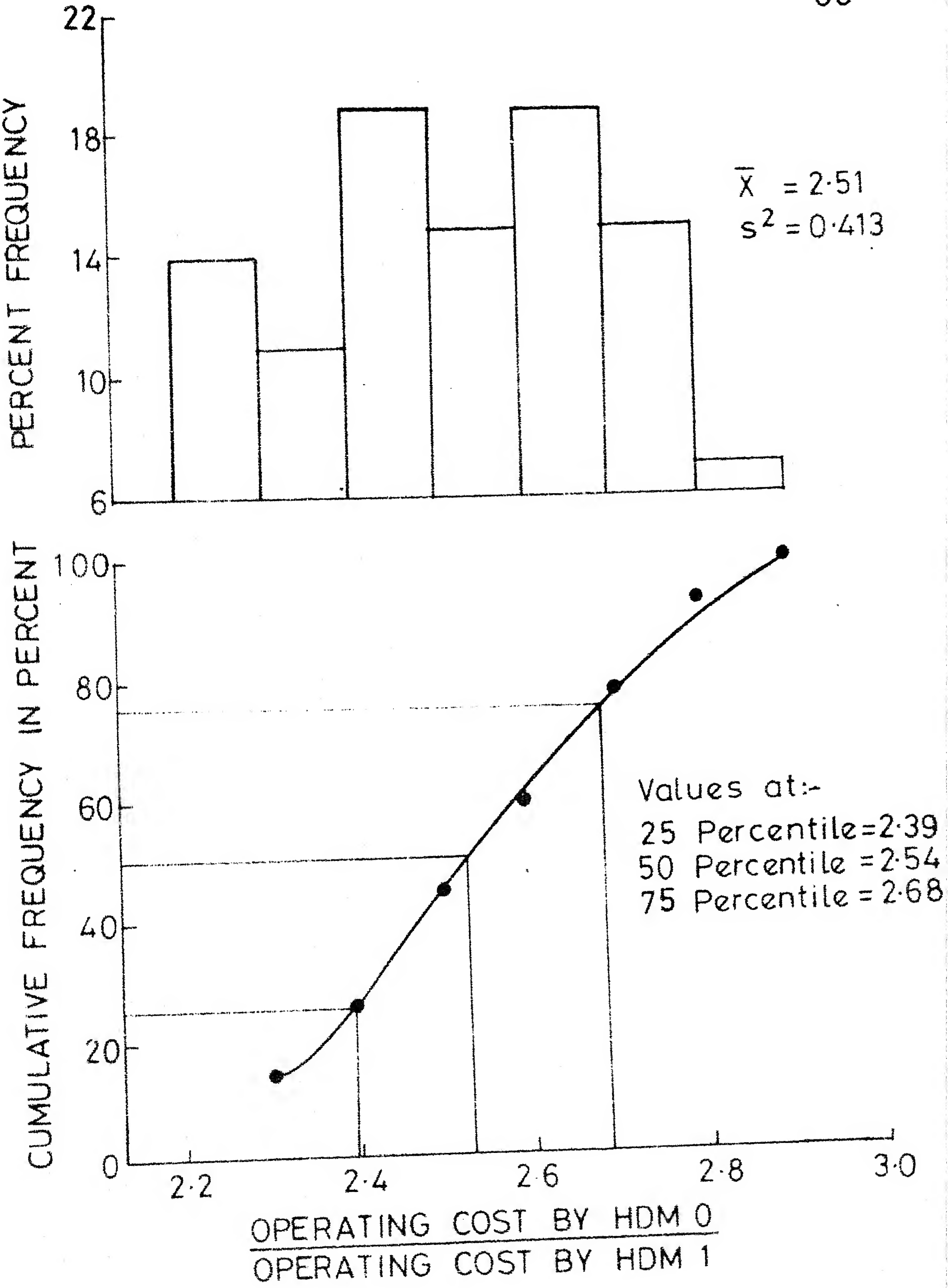


FIG.4·2 RATIO OF OPERATING COST OF HDM 0 AND HDM 1 VS TRAFFIC VOLUME



HDM 0 = Original Kenya Model

HDM 1 = HDM 0, Wherein vehicle operating cost sub-model is modified for Indian conditions

FIG. 4·3 DISTRIBUTION OF RATIO OF OPERATING COSTS OF HDM 0 AND HDM 1

TABLE 4.7

T-TEST HDMO VS HDM1 VEHICLE OPERATING COSTS

Degrees of Freedom	Mean		T-Statistic	'T' from Tables at 5 percent level	Remarks
	HDMO	HDM1			
22	484.833	189.333	3.488	1.717	
22	491.000	191.750	3.488	1.717	Significant at 5 percent for all alternatives for PV01 and PV02.
22	368.833	138.000	3.099	1.717	
22	386.583	146.083	4.362	1.717	
22	428.666	163.916	3.716	1.717	
22	370.583	138.750	4.023	1.717	

In other words the values given by HDM1 are more relevent to the Indian conditions.

4.5.2 Comparison of Results from HDM1 and HDM2:- The model version HDM2 includes all the modifications for the Indian conditions incorporated in the model version HDM1. Besides that the effect of traffic interactions is also included by incorporating speed-flow relationships based on the results of the Indian study. The comparison of the outputs from HDM1 and HDM2 is made in the succeeding paragraphs to study the sensitivity of the traffic interactions on the vehicle operating cost and the vehicle travel time cost.

The values of the average operating speeds obtained from the two models are given in Table 4.8. The values by the two models are generally comparable with the observed values in the Table 4.3. The results indicate that the model version HDM1 gives higher values of the operating speed which does not get affected by the traffic volume. Further difference in the operating speeds of the two versions increases over time. This is because of the increased traffic flow over time.

The vehicle travel time cost values obtained from the two model versions are given in Table 4.9. As observed from the table, for the first few years when the traffic volume is not very high the difference of values between the two

TABLE 4.8

AVERAGE SPEED IN LINK 1001 (PV01)
(HDM2 VS HDM1)

Year	Traffic Volume	Average Speed Km/hour			
		Pass Car		Larg Bus	
		HDM2	HDM1	HDM2	HDM1
1983	2678	52.5	54.4	42.8	44.1
1984	3418	49.7	52.2	40.9	42.6
1985	3991	42.3	45.3	35.9	37.9
1986	4663	42.8	46.2	36.3	38.5
1987	5452	35.5	39.5	31.4	34.0
1988	6377	38.7	43.1	33.5	36.4
1989	7464	38.5	43.6	33.3	36.7

HDM1 - Kenya model wherein vehicle operating cost submodel is modified for Indian conditions (free flow conditions)

HDM2 - HDM1 wherein traffic interactions taken into account

TABLE 4.9

COMPARISON OF VEHICLE TRAVEL TIME COSTS

BASED ON HDM1 AND HDM2 MODEL VERSIONS

Year	Traffic	Travel Time Cost		HDM2 / HDM1	Remarks
		HDM2	HDM1		
1983	2099	83.563	80.292	1.04	PV02-ALTO
1984	2678	106.487	101.468	1.05	
1985	3418	136.153	127.472	1.07	
1986	3991	158.928	147.102	1.08	
1987	4663	185.920	169.765	1.09	
1988	5452	218.071	195.933	1.11	
1989	6377	256.604	226.148	1.13	
1990	7464	303.127	261.039	1.16	
1991	8741	359.812	301.331	1.19	
1992	10243	429.664	347.864	1.23	
1993	12010	516.973	401.607	1.29	
1994	14089	628.084	463.680	1.35	

HDM1 - Kenya model wherein vehicle operating submodel is modified for Indian conditions (free flow conditions).

HDM2 - HDM1, wherein traffic interactions taken into account.

versions is not very significant. But at comparatively higher traffic volume in later years the average variation in the cost is about 20 percent. The magnitude of travel time cost under free flow conditions is less. This variation of cost is solely because of the speed volume effect i.e. traffic interactions. Frequency distribution and cumulative frequency for the ratio of the travel time costs by HDM1 and HDM2 are shown in Fig. 4.4. The mean is quite close to the 50 percentile value. F - Test carried out on all the alternatives is given in Table 4.10. The test implies that the difference in the individual alternatives is significant at more than 5 percent level.

The vehicle operating costs obtained from the two model versions are given in Table 4.11. As evident from the table the values given by the two models for all the alternatives vary from 1 percent to 5 percent only. Statistical F - Test results as given in Table 4.12 show that the values of the two models differ only within individual alternatives at 5 percent level.

4.5.3 Discussion of Outputs from HDM2: - As mentioned in the section 4.4, four different runs are taken for each model version. The input data is given in the table form in the model output which helps the user to detect inconsistencies and numerical errors that have escaped during

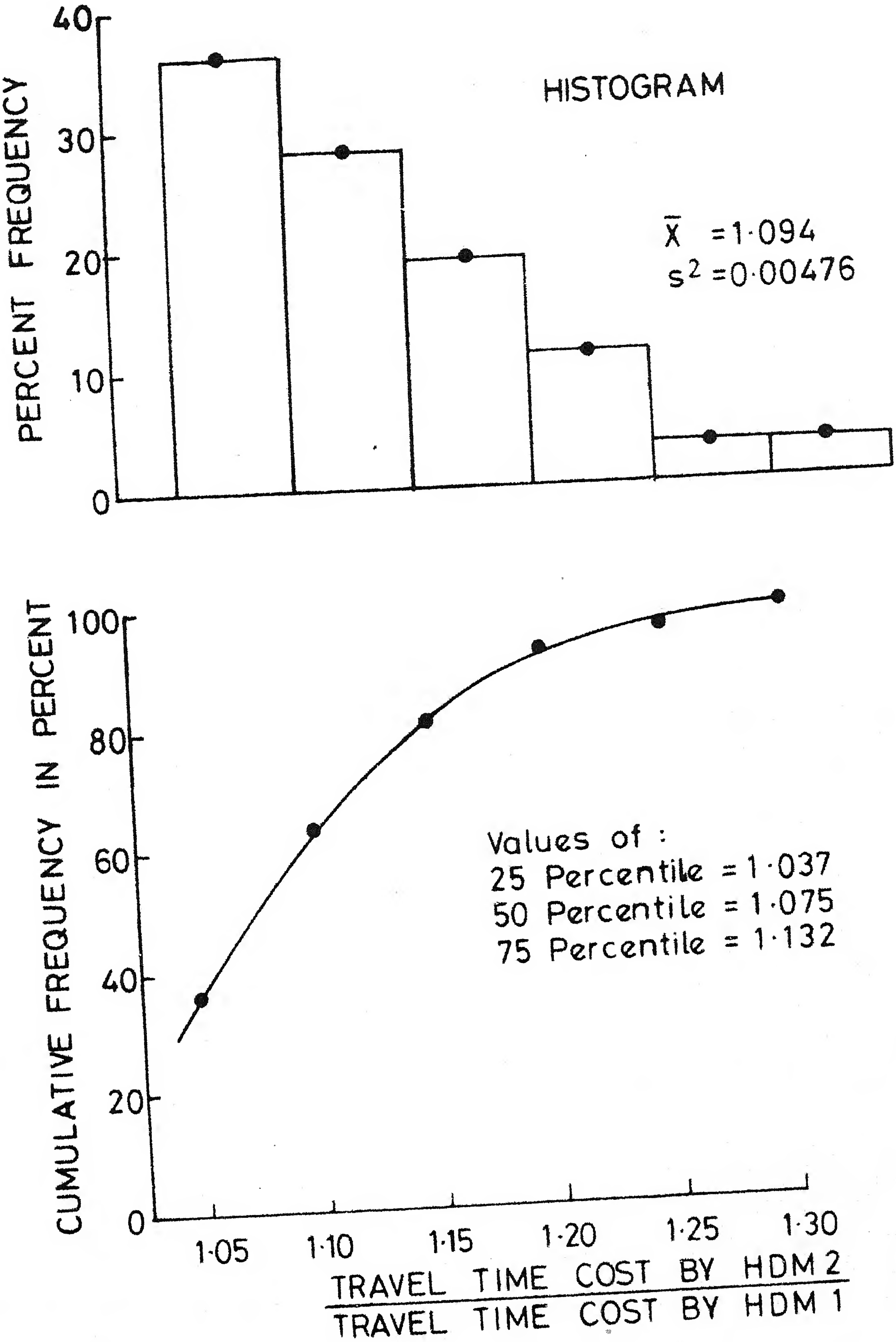


FIG. 4·4 DISTRIBUTION OF RATIO OF TRAVEL TIME COSTS OF HDM 1 AND HDM 2

TABLE 4.10

F-TEST HDM1 VS HDM2 VEHICLE TRAVEL TIME COST

Source of Variation	Degrees of Freedom	F Statistic	F At 5 % Level	Remarks
Within an individual alternative	1	1.5094	3.84	The two model results are same
Between alternatives	5	1.9986	2.21	The two model results vary at levels more than 5 percent

TABLE 4.11

COMPARISON OF VEHICLE OPERATING COSTS

OF HDM1 AND HDM2 MODEL VERSIONS

Year	Traffic Volume	Vehicle Operating Cost		HDM2 / HDM1	Remarks
		HDM2	HDM1		
1983	2099	67.123	66.665	1.01	PV01-ALTO
1984	2678	83.645	82.912	1.01	
1985	3418	105.553	104.351	1.01	
1986	3991	121.439	119.796	1.01	
1987	4663	140.055	137.796	1.02	
1988	5452	161.700	158.578	1.02	
1989	6377	186.884	182.549	1.02	
1990	7464	216.220	210.170	1.03	
1991	8741	251.020	242.499	1.04	
1992	10243	291.672	279.597	1.04	
1993	12010	339.472	322.221	1.05	
1994	14089	396.177	371.254	1.06	

TABLE 4.12

F-TEST HDM1 VS HDM2 VEHICLE OPERATING COST

Source of Variation	Degrees of Freedom	F Statistic	F At 5 % Level	Remarks
Within an individual alternative	1	0.035	3.84	The two model results are same
Between alternatives	5	2.743	2.21	The two model results vary between alternatives

the data reading. Besides this, ten output reports are also printed. These reports are briefly discussed as follows:

Report type 1 (Table 4.13) is a summary of road maintenance for the complete analysis period at a specified discount rate. It gives cost breakdown of various maintenance operations in a group alternative. Report type 2 (Table 4.14) is an annual road maintenance report which gives costs and quantities for various maintenance operations for various sections and links of both paved and unpaved roads. Report type 3 (Table 4.15) gives average daily traffic (ADT) for different vehicles for all the analysis years. It also gives road user cost details viz., vehicle operating cost per vehicle trip and vehicle operating cost per vehicle km. Report type 4 (Table 4.16) provides the user with the updated annual road conditions for various link alternatives for each analysis year. It includes gravel thickness, roughness, rut depth, and looseness for unpaved roads, and roughness, cracking etc. for paved roads.

Report type 6 (Table 4.17) gives the discounted economic costs of various links and group alternatives. It also gives normal and generated ADT for various analysis years. The normal and generated traffic curves for the analysis period are shown in Fig. 4.5. The normal traffic is increasing

TABLE 4.13

REPORT TYPE 1

SUMMARY ROAD MAINTENANCE REPORT

IN MILLION RUPEES

COST BREAKDOWN BY MAINTENANCE OPERATION

	TOTAL COST	GRADING DRY SEASON (KM)	GRADING WET SEASON (KM)	SPOT GRAVEL (CU.M)	REGRAVEL (CU.M)	ROUTINE UNPAVED (KM)	PATCHING (SQ.M)	SURFACE DRESSING (SQ.M)	OVERLAY (CU.M)
GROUP-ALT: GUNP-ALTO									
1983-1994 AT 0.0 %									
FINANCIAL COST									
LABOR	27.624	5.310	10.923	4.126	0.993	6.273	0.000	0.000	0.000
EQUIPMENT	59.963	16.242	30.199	4.126	5.869	3.528	0.000	0.000	0.000
MATERIALS	31.499	6.559	16.706	5.010	1.264	1.960	0.000	0.000	0.000
OVERHEAD	13.232	3.123	6.425	1.474	0.903	1.307	0.000	0.000	0.000
TOTAL	132.318	31.234	64.252	14.735	9.029	13.068	0.000	0.000	0.000
ECONOMIC COST									
LABOR	27.624	5.310	10.923	4.126	0.993	6.273	0.000	0.000	0.000
EQUIPMENT	59.963	16.242	30.199	4.126	5.869	3.528	0.000	0.000	0.000
MATERIALS	31.499	6.559	16.706	5.010	1.264	1.960	0.000	0.000	0.000
OVERHEAD	13.232	3.123	6.425	1.474	0.903	1.307	0.000	0.000	0.000
TOTAL	132.318	31.234	64.252	14.735	9.029	13.068	0.000	0.000	0.000
TOTAL QUANTITY		8924.	8924.	159300.	106852.	1452.	0.	0.	0.

TABLE 4.14

REPORT TYPE 2

ANNUAL ROAD MAINTENANCE REPORT

IN MILLION RUPEES

SECTION OR LINK	MAINT. STANDARD	TOTAL COST	GRADING DRY SEASON (KM)	GRADING WET SEASON (KM)	SPOT GRAVEL (CU.M)	REGRAVEL (CU.M)	ROUTINE UNPAVED (KM)	PATCHING (SQ.M)	SURFACE DRESSING (SQ.M)	OVERLAY (CU.M)
			QUANTITIES USED BY MAINTENANCE OPERATION							
1984 LINK-ALT: PV01-ALTO										
1001	ASAO		0.	0.	0.	0.	0.	14700.	0.	0.
LINK TOTAL			0.	0.	0.	0.	0.	14700.	0.	0.
TOTAL FINANCIAL COST		0.769	0.000	0.000	0.000	0.000	0.000	0.034	0.000	0.000
TOTAL ECONOMIC COST		0.769	0.000	0.000	0.000	0.000	0.000	0.034	0.000	0.000
FOREIGN EXCHANGE (%)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1985 LINK-ALT: PV01-ALTO										
1001	ASAO		0.	0.	0.	0.	0.	14700.	0.	0.
LINK TOTAL			0.	0.	0.	0.	0.	14700.	0.	0.
TOTAL FINANCIAL COST		0.769	0.000	0.000	0.000	0.000	0.000	0.034	0.000	0.000
TOTAL ECONOMIC COST		0.769	0.000	0.000	0.000	0.000	0.000	0.034	0.000	0.000
FOREIGN EXCHANGE (%)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1986 LINK-ALT: PV01-ALTO										
1001	ASAO		0.	0.	0.	0.	0.	14700.	0.	0.
LINK TOTAL			0.	0.	0.	0.	0.	14700.	0.	0.
TOTAL FINANCIAL COST		0.769	0.000	0.000	0.000	0.000	0.000	0.034	0.000	0.000
TOTAL ECONOMIC COST		0.769	0.000	0.000	0.000	0.000	0.000	0.034	0.000	0.000
FOREIGN EXCHANGE (%)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SECTION		PASS CAR	LARG BUS	HV TRUCK
LINK	ADT - NORMAL	944.6	317.5	836.5
	ADT - GENERATED	0.0	0.0	0.0
	EQUIV. STANDARD AXLES	0.	111.	4099.
1001	AV. SPEED (KM/HR)	28.7	24.5	24.5
	VOC PER VEHICLE-TRIP	222.29	525.44	27.95
	VOC PER VEHICLE-KM	5.293	12.510	0.666
LINK	ADT - NORMAL	1190.2	400.1	1087.5
	ADT - GENERATED	178.5	80.0	271.9
	EQUIV. STANDARD AXLES	0.	168.	6661.
1001	AV. SPEED (KM/HR)	52.5	42.8	42.8
	VOC PER VEHICLE-TRIP	85.01	310.91	22.09
	VOC PER VEHICLE-KM	2.024	7.403	0.526
LINK	ADT - NORMAL	1499.7	504.1	1413.8
	ADT - GENERATED	225.0	100.8	353.4
	EQUIV. STANDARD AXLES	0.	212.	8659.
1001	AV. SPEED (KM/HR)	49.7	40.9	40.9
	VOC PER VEHICLE-TRIP	96.20	323.00	21.76
	VOC PER VEHICLE-KM	2.291	7.691	0.518
LINK	ADT - NORMAL	1709.6	584.7	1696.5
	ADT - GENERATED	256.4	116.9	424.1
	EQUIV. STANDARD AXLES	0.	246.	10391.
1001	AV. SPEED (KM/HR)	42.3	35.9	35.9
	VOC PER VEHICLE-TRIP	140.26	363.74	22.36
	VOC PER VEHICLE-KM	3.340	8.661	0.532
LINK	ADT - NORMAL	1949.0	678.3	2035.8
	ADT - GENERATED	256.4	116.9	424.1
	EQUIV. STANDARD AXLES	0.	278.	12054.
1001	AV. SPEED (KM/HR)	42.8	36.3	36.3
	VOC PER VEHICLE-TRIP	134.87	360.68	22.39
	VOC PER VEHICLE-KM	3.211	8.588	0.533

TABLE 4.16

REPORT TYPE 4

ANNUAL ROAD CONDITIONS REPORT

				YEARS SINCE LAST		UNPAVED ROADS									
						YEARLY GRAVEL THICKNESS		MEAN YEARLY VALUES						MEAN YEARLY VALUES	
								ROUGHNESS				MOD SN.			
YEAR	LINK-ALT.	SECTION	SURFACE ID CODE	REGRAV/ RESURF	CHIP SEAL	BEG. (MM)	END (MM)	DRY (MM/KM)	WET (MM/KM)	RUT DEPTH (MM)	LOOSE -NESS (MM)	DRY	WET	ROUGHNESS (MM/KM)	CRACKING (SQ.M/KM)
1983	PV01-ALTO	1001	ASAC	8	0							1.5	1.3	9000.	3500.
1984	PV01-ALTO	1001	ASAC	9	1							1.6	1.2	9000.	3500.
1985	PV01-ALTO	1001	ASAC	10	2							1.5	1.2	9000.	3500.
1986	PV01-ALTO	1001	ASAC	11	3							1.5	1.2	9000.	3500.
1987	PV01-ALTO	1001	ASAC	12	4							1.5	1.2	9000.	3500.
1988	PV01-ALTO	1001	ASAC	13	0							1.5	1.2	9000.	3500.
1989	PV01-ALTO	1001	ASAC	14	1							1.6	1.2	9000.	3500.
1990	PV01-ALTO	1001	ASAC	15	2							1.5	1.2	9000.	3500.
1983	PV02-ALTO	1002	ASAC	4	3							1.5	1.3	9000.	3500.
1984	PV02-ALTO	1002	ASAC	5	4							1.3	1.1	9000.	3500.
1985	PV02-ALTO	1002	ASAC	6	0							1.3	1.1	9000.	3500.
1986	PV02-ALTO	1002	ASAC	7	1							1.3	1.1	9000.	3500.
1987	PV02-ALTO	1002	ASAC	8	2							1.3	1.0	9000.	3500.
1988	PV02-ALTO	1002	ASAC	9	3							1.3	1.0	9000.	3500.
1989	PV02-ALTO	1002	ASAC	10	4							1.3	1.0	9000.	3500.
1990	PV02-ALTO	1002	ASAC	11	0							1.3	1.0	9000.	3500.
1983	UP01-ALTO	1003	LATR	5		150.	135.	9557.	9877.	12.	5.				
1984	UP01-ALTO	1003	LATR	6		135.	118.	9557.	9834.	12.	5.				
1985	UP01-ALTO	1003	LATR	0		118.	100.	9557.	9796.	12.	5.				

NOTE : END-OF-YEAR VALUES REPRESENT ROAD SURFACE CONDITIONS BEFORE APPLICATION OF GRAVEL RESURFACING, PATCHING, OVERLAYING OR REHABILITATION.

TABLE 4.17

REPORT TYPE 6

ECONOMIC COSTS OF ALTERNATIVE REPORT

IN MILLION RUPEES

LINK-ALT. PV01-ALT1

SIMLA TO SOLAN - ORIGINAL LENGTH 42.0 KM

YEAR	ANNUAL ADT NORMAL	ANNUAL ADT GENER.	ANNUAL ESAL	CAPITAL/ CONSTR. COSTS	ROAD MAINT. COSTS	EXISTING VEHICLE OPERATING COSTS	GENERATED VEHICLE OPERATING COSTS	EXISTING VEHICLE TRAVEL TIME COSTS	GENERATED VEHICLE TRAVEL TIME COSTS	NET EXOGENOUS COSTS
1983	2099.	0.	4210.	100.000	1.558	67.123	0.000	78.951	0.000	0.000
1984	2678.	530.	6829.	100.000	0.786	34.997	6.426	56.105	10.386	-0.600
1985	3418.	679.	8871.	0.000	0.803	49.151	8.869	74.166	13.722	-0.600
1986	3991.	798.	10637.	0.000	1.617	80.665	13.935	98.345	18.183	-0.600
1987	4663.	798.	12332.	0.000	0.803	89.551	13.487	112.329	18.000	-0.640
1988	5452.	798.	14365.	0.000	10.295	134.549	17.167	151.654	21.016	-0.680
1989	6377.	798.	16803.	0.000	0.759	135.629	15.194	163.133	19.608	-0.720
1990	7464.	798.	19728.	0.000	0.792	154.217	15.006	189.184	19.701	-0.760
1991	8741.	798.	23234.	0.000	1.617	181.413	15.297	223.998	20.206	-0.800
1992	10243.	798.	27440.	0.000	0.776	183.261	13.502	244.407	19.111	-0.840
1993	12010.	798.	32484.	0.000	0.803	234.175	14.851	304.532	20.615	-0.880
1994	14089.	798.	38534.	-20.000	10.295	345.000	18.797	429.995	25.171	-0.920
TOTAL COSTS/BENEFITS - UNDISCOUNTED:										
			ECONOMIC:	180.000	30.903	1689.732	152.532	2126.797	205.719	-8.040
			FOREIGN:	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DISCOUNTED ECONOMIC COSTS AT :										
			0.0 %	180.000	30.903	1689.732	152.532	2126.797	205.719	-8.040
			8.0 %	184.015	18.844	984.671	94.504	1240.279	128.022	-5.031
			10.0 %	183.899	16.927	874.126	84.966	1101.460	115.267	-4.539
			15.0 %	182.658	13.275	665.905	66.463	840.153	90.531	-3.586
			25.0 %	178.282	8.942	426.356	43.819	539.816	60.263	-2.425

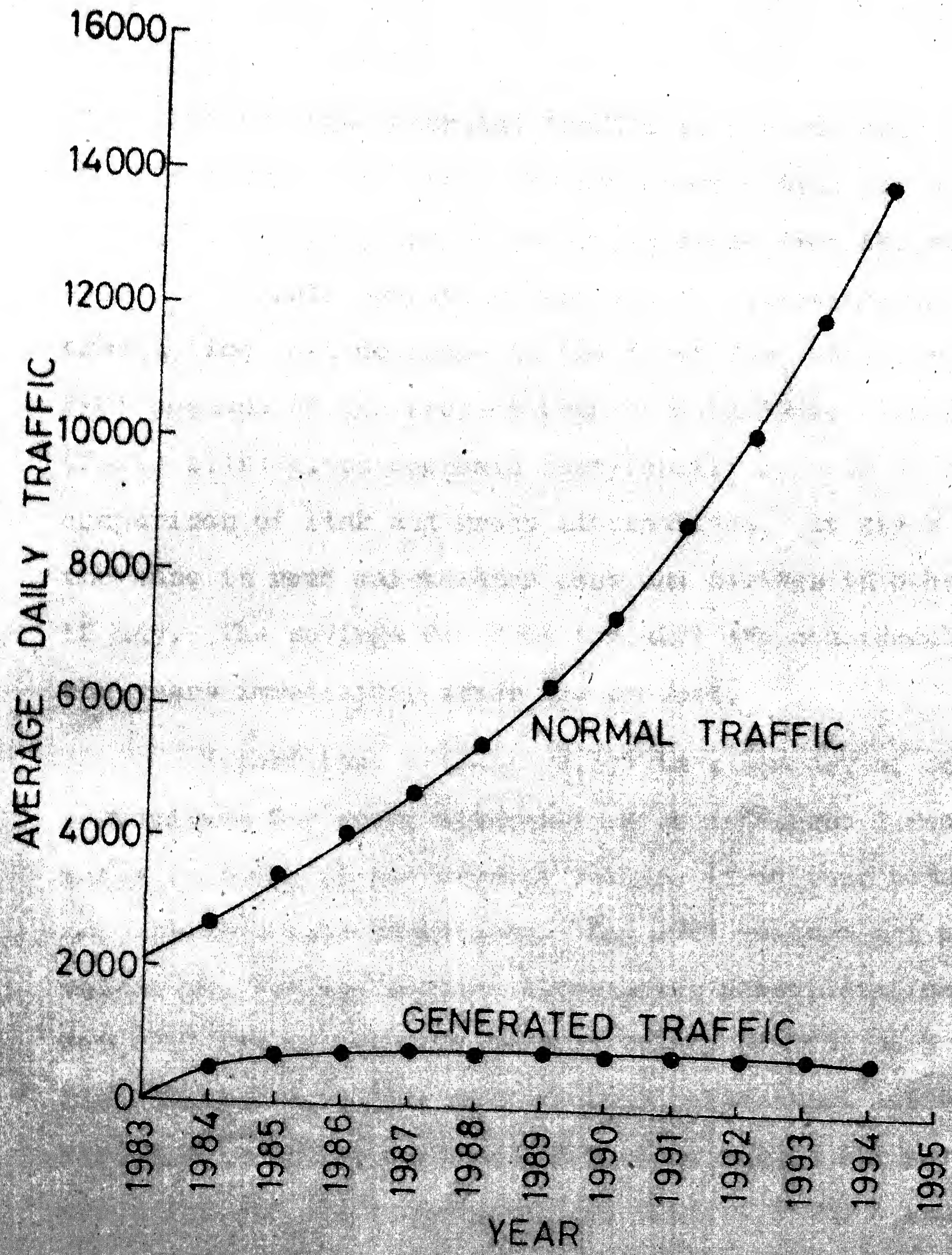


FIG.4.5 GROWTH OF AVERAGE DAILY TRAFFIC WITH TIME

with time but the generated traffic is induced only in the first two years after the new construction project and thereafter it remains constant. As clear from the report the existing vehicle operating cost and the existing vehicle travel time cost decrease in the first few years for the link PV01 because of the project completed in 1984. Report type 7 (Table 4.18) gives economic cost/benefit reports of pairwise comparison of link and group alternatives. It gives relative increase in road maintenance cost and savings in other costs if any. The savings for PV01 for ALT1 are considerable for the years immediately after the project.

Report type 8 (Table 4.19) is a summary of economic comparisons for group alternatives at different discount rates in terms of net present values, first year benefits and internal rate of returns. For PV01 maximum net present values are for the project alternative rehabilitation ALT1. For PV02 the maximum net present values are for ALT3 i.e. overlay with intensive routine maintenance activities. Fig. 4.6 shows the maximum net present values for paved group for various discount rates. Fig. 4.7 shows internal rate of return curve for a paved link corresponding to different alternatives. Report type 9 (Table 4.20) is a summary comparison of alternatives for all links by different discount rates. Report type 10 (Table 4.21) is regarding

TABLE 4.18

REPORT TYPE 7

COMPARISON OF ALTERNATIVES REPORT : BASE

IN MILLION RUPEES

COMPARISON : PV01-ALT1 VS PV01-ALT0

LINK PV01 : SIMLA TO SOLAN - ORIGINAL LENGTH 42.0 KM

ECONOMIC BENEFIT/COST STREAMS OF ALTERNATIVE ALT1 RELATIVE TO ALTERNATIVE ALT0

YEAR	INCREASE IN CAPITAL/ CONSTRUCTION COSTS (1)	INCREASE IN ROAD MAINTENANCE COSTS (2)	SAVINGS IN EXISTING VEHICLE OPERATING COSTS (3)	GENERATED VEHICLE OPERATING BENEFITS (4)	SAVINGS IN EXISTING VEHICLE TRAVEL TIME COSTS (5)	GENERATED VEHICLE TRAVEL TIME BENEFITS (6)	NET EXOGENOUS BENEFITS (7)	TOTAL ECONOMIC BENEFITS (8=-1-2+3+4+5
1983	100.000	0.000	0.000	0.000	0.000	0.000	0.000	-100.000
1984	100.000	0.017	48.648	3.754	44.444	4.088	0.600	1.518
1985	0.000	0.034	56.402	4.359	54.293	4.994	0.600	120.614
1986	0.000	0.848	40.773	3.183	51.495	4.748	0.600	99.951
1987	0.000	0.034	50.504	3.445	62.812	5.017	0.640	122.384
1988	0.000	8.737	27.151	1.651	53.570	3.722	0.680	78.037
1989	0.000	-0.009	51.255	2.691	78.064	4.685	0.720	137.425
1990	0.000	0.023	62.003	2.844	95.333	4.955	0.760	165.872
1991	0.000	0.848	69.607	2.794	113.131	5.093	0.800	190.577
1992	0.000	0.007	108.411	3.789	157.297	6.128	0.840	276.458
1993	0.000	-0.756	105.300	3.224	177.484	5.991	0.880	293.634
1994	-20.000	9.526	51.177	1.385	153.595	4.503	0.920	222.054
TOTAL COSTS/BENEFITS - UNDISCOUNTED:								
ECONOMIC:	180.000	19.309	671.232	33.119	1041.518	53.924	8.040	1608.524
FOREIGN:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
ECONOMIC BENEFITS DISCOUNTED AT:								
0.0 %	180.000	19.309	671.232	33.119	1041.519	53.924	8.040	1608.524
8.0 %	184.015	10.894	412.408	22.243	603.918	34.423	5.031	883.114
10.0 %	183.899	9.581	370.560	20.402	534.861	31.198	4.539	768.080
15.0 %	162.658	7.106	290.204	16.761	404.276	24.915	3.586	549.980
25.0 %	178.282	4.229	193.846	12.119	252.750	17.146	2.425	295.775

TABLE 4.19

REPORT TYPE 8

SUMMARY OF COMPARISON OF ALTERNATIVES BY GROUP REPORT : BASE

IN MILLION RUPEES

DESCRIPTION	ORIGINAL LENGTH	TOTAL UNDISCOUNTED ECONOMIC COST ALTERNATIVE	VS. ALTERNATIVE	DISCOUNT RATE (%)	NET PRESENT VALUE	FIRST YEAR BENEFITS (%)	INTERNAL RATE OF RETURN (%)
LINK PV01 SIMLA TO KALKA	42.0 KM	ALT1	VS. ALT0			60.3	70.0
		4377.644	5540.873	0.0	1608.524		
				8.0	883.114		
				10.0	768.080		
				15.0	549.980		
				25.0	295.775		
LINK PV02 SOLAN TO KALKA	42.0 KM	ALT3	VS. ALT0			-8.9	43.7
		4384.695	5792.848	0.0	1408.154		
				8.0	706.241		
				10.0	597.303		
				15.0	393.843		
				25.0	165.076		
GROUP GPAV PAVED ROADS	84.0 KM	ALT3	VS. ALT0			37.5	55.4
		8762.338	11333.721	0.0	3016.678		
				8.0	1599.355		
				10.0	1365.383		
				15.0	943.823		
				25.0	460.850		

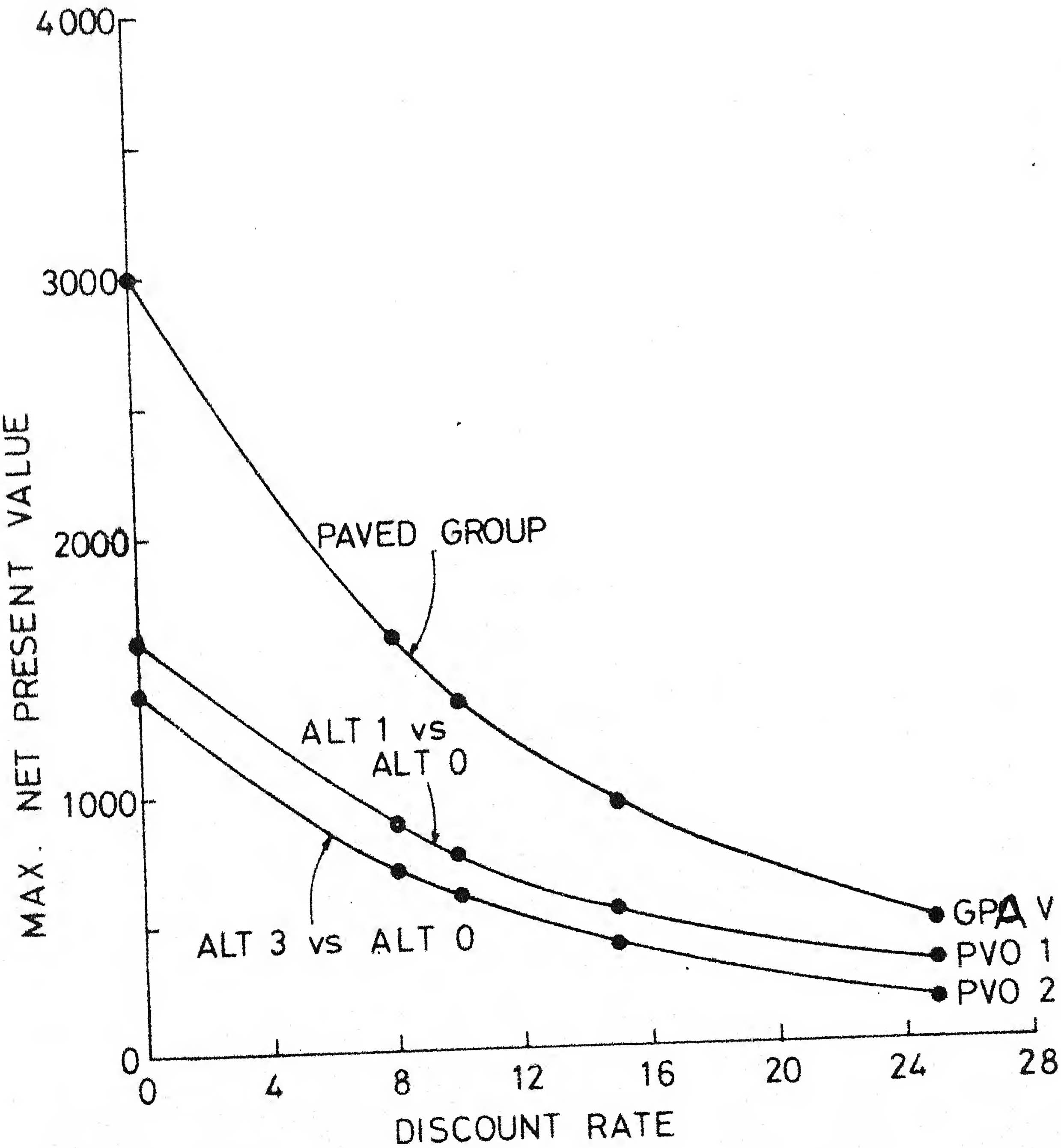


FIG. 4·6 MAXIMUM NET PRESENT VALUE VS DISCOUNT RATE

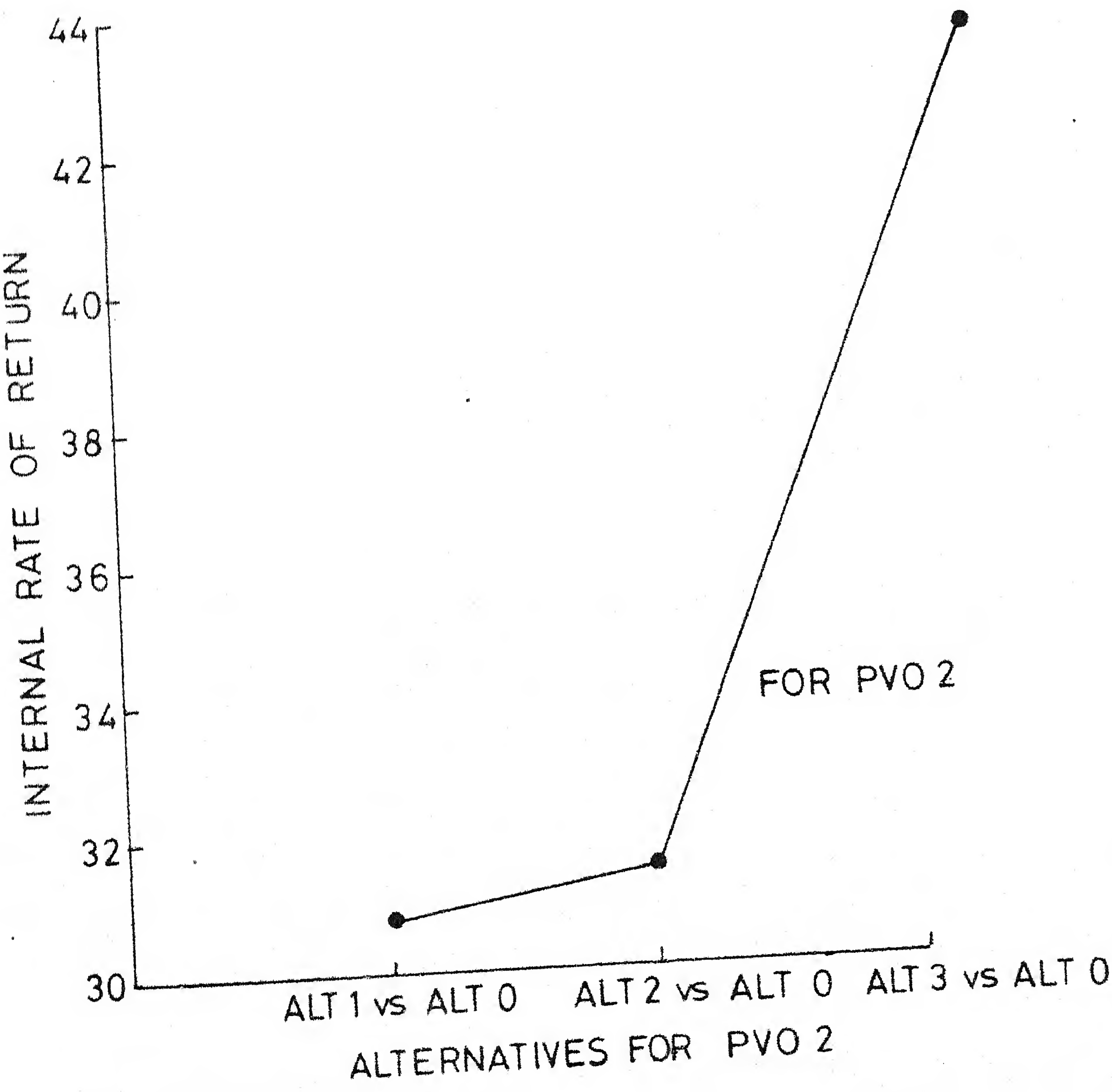


FIG. 4·7 INTERNAL RATE OF RETURN FOR LINK PVO 2

TABLE 4.20

REPORT TYPE 9

SUMMARY OF COMPARISON OF ALTERNATIVES BY DISCOUNT RATE REPORT : BASE

IN MILLION RUPEES

DISCOUNT RATE = 8.0 %	ORIGINAL LENGTH	ALTERNATIVES	NET PRESENT VALUE	INTERNAL RATE OF RETURN - %
LINK PV01 : SIMLA TO SOLAN	42. KM	ALT1 VS. ALT0	883.114	70.0
LINK PV02 : SOLAN TO KALKA	42. KM	ALT1 VS. ALT0	510.154	30.8
GROUP GPAV : PAVED ROADS	84. KM	ALT1 VS. ALT0	1393.268	47.3
LINK PV01 : SIMLA TO SOLAN	42. KM	ALT1 VS. ALT0	883.114	70.0
LINK PV02 : SOLAN TO KALKA	42. KM	ALT2 VS. ALT0	332.160	31.5
GROUP GPAV : PAVED ROADS	84. KM	ALT2 VS. ALT0	1215.274	50.7
LINK PV01 : SIMLA TO SOLAN	42. KM	ALT1 VS. ALT0	883.114	70.0
LINK PV02 : SOLAN TO KALKA	42. KM	ALT3 VS. ALT0	706.241	43.7
GROUP GPAV : PAVED ROADS	84. KM	ALT3 VS. ALT0	1589.355	55.4
LINK UP01 : MIXED GRAVEL RDS	56. KM	ALT1 VS. ALT0	92.752	15.8
LINK UP02 : MIXED EARTH RDS	65. KM	ALT1 VS. ALT0	-100.000	NONE
GROUP GUNP : UNPAVED ROADS	121. KM	ALT1 VS. ALT0	-7.248	7.6
LINK UP01 : MIXED GRAVEL RDS	56. KM	ALT2 VS. ALT0	10.450	8.7
LINK UP02 : MIXED EARTH RDS	65. KM	ALT2 VS. ALT0	-107.298	NONE
GROUP GUNP : UNPAVED ROADS	121. KM	ALT2 VS. ALT0	-96.848	3.3
LINK UP01 : MIXED GRAVEL RDS	56. KM	ALT2 VS. ALT0	10.450	8.7
LINK UP02 : MIXED EARTH RDS	65. KM	ALT3 VS. ALT0	-115.276	NONE
GROUP GUNP : UNPAVED ROADS	121. KM	ALT3 VS. ALT0	-104.826	2.8

TABLE 4.21

REPORT TYPE 10

OPTIMIZATION OF LINK ALTERNATIVES BY GROUP REPORT : BASE

IN MILLION RUPEES

THIS TABLE GIVES RESULTS OF SENSITIVITY ANALYSIS FOR ALL LINKS COMBINED FOR THE SPECIFIED DISCOUNT RATES. FOR EACH DISCOUNT RATE, ALTERNATIVES WHICH MAXIMIZE THE NET PRESENT VALUE ARE SELECTED FOR EACH LINK, AND AGGREGATED TO YIELD MAXIMUM NET PRESENT VALUE FOR THE GROUP.

DISCOUNT RATE = 8.0 %	ORIGINAL LENGTH	ALTERNATIVES	NET PRESENT VALUE		INTERNAL RATE OF RETURN = %
GROUP GPAV : PAVED ROADS	84. KM				
LINK PV01 : SIMLA TO SOLAN	42. KM	ALT1 VS. ALT0	883.114		70.0
LINK PV02 : SOLAN TO KALKA	42. KM	ALT3 VS. ALT0	706.241		43.7
		ALT1 VS. ALT0	510.154		30.6
		ALT2 VS. ALT0	332.160		31.5
MAXIMUM NET PRESENT VALUE FOR GROUP GPAV IS			1589.355	AT	8.0 % DISCOUNT RATE
GROUP GUNP : UNPAVED ROADS	121. KM				
LINK UP01 : MIXED GRAVEL RDS	56. KM	ALT1 VS. ALT0	92.752		15.8
		ALT2 VS. ALT0	10.450		8.7
LINK UP02 : MIXED EARTH RDS	65. KM	ALT1 VS. ALT0	-100.000		NONE
		ALT2 VS. ALT0	-107.298		NONE
		ALT3 VS. ALT0	-115.276		NONE
MAXIMUM NET PRESENT VALUE FOR GROUP GUNP IS			-7.248	AT	8.0 % DISCOUNT RATE

economic optimization of link-alternatives, in terms of maximizing the net present value, for each group of links at different discount rates.

In the present case under investigation maximum internal rate of return for PV01 is 70 percent and for PV02 is 43.7 percent. The output further indicates that for maximum net present values the following optimum investment be implemented: (i) For the link PV01 rehabilitation project be taken up in 1983-84. (ii) For the link PV02 overlay with intensive routine maintenance activities gives maximum values.

Comparison of unpaved alternatives were not analysed because the relationships for resource consumptions and speeds for various modes are not yet developed in India. The relationships for paved roads have been used in the present case for unpaved roads also. This part of the model be further refined when results for unpaved roads become available.

5 SUMMARY AND CONCLUSION

The Highway Design and Maintenance (HDM) Model of the World Bank calculates costs for various alternatives of highway design and maintenance options for a given highway project. It estimates total cost on a year by year basis and thus can be used to search for the alternatives with the lowest total cost. The model further helps in decision making when the construction and maintenance policies are seen against the backdrop of the total transportation cost of a set of alternative road investments. The types of decisions taken by the model include the choice of alignment, geometric standard, surface type, maintenance policy, and construction and maintenance methods. Besides this the various submodels of the HDM also predict the deterioration of the road surface and quantities for each of the maintenance and construction projects required by the specified policy. Such information can be very useful for planning as well as execution of the highway projects.

Various submodels of the HDM model have been caliberated based on the Kenya study by the TRRL. Only in 1977 RUCS was sponsored jointly by the Government of India and the World Bank to investigate the road user cost on Indian highways. In India not much work has been done to develop the model for

estimating the total highway transportation cost. The unique features of the Indian Highways cannot be explained by the research carried out in the other countries. There is a need to incorporate the results of the RUCS in caliberating various submodels of the HDM model to make it applicable for Indian conditions. The preliminary results from the RUCS have very recently been made available. The vehicle operating cost submodel and the associated computer programme of the HDM have been modified in the present study.

Kalka Simla Road has been selected to study the application of the Kenya model. A number of alternate road investment strategies are selected. Experimental runs are taken from the three model versions of the HDM model, namely: (a) original version of the model based on the Kenya studies ,HDMO (b) modified version HDM1, wherein results of the RUCS have been incorporated under free flow conditions (c) modified version HDM2 wherein effect of traffic interactions is also introduced. While comparing HDMO and HDM1 it was observed that the vehicle operating speeds computed by HDMO version are much low compared to the values found by the field studies, whereas the values given by HDM1 version are quite comparable. Further the values of the vehicle operating cost and vehicle travel time cost in respect of HDMO version are considerably higher than those of HDM1 version. But both HDMO and HDM1 versions do not include traffic interactions. The HDM2 version which incorporates traffic interactions is more relevent to the Indian conditions.

5.1 Suggestions for Future Study

In the present study only vehicle operating cost submodel of the HDM model has been modified. The suggestions for future studies for both paved and unpaved roads are as under:

(i) The vehicle operating cost submodel modified for Indian conditions (HDM2) requires further modification as and when the operating cost relationships for the vehicles other than bus and truck are developed.

(ii) When the relationships for the various highway deterioration maintenance policies, construction options etc. are developed, the other submodels namely: Construction submodel, Road Deterioration and maintenance submodel, Exogenous costs/Benefits submodel should also be modified for Indian conditions.

The total transportation cost obtained by modifying the entire World Bank model will aid in planning the construction and maintenance strategies quite effectively. Within the some available funds and the budget constraints many for more useful projects can be undertaken.

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